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# THE PSYCHOLOGICAL BULLETIN

## VISUAL SENSATIONS: A REVIEW OF RECENT LITERATURE

BY MARION R. STOLL

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Two years ago, Sloan (119) reviewed the literature on visual sensations for 1926 and 1927. The publications of the succeeding eighteen months are considered in the present paper.[1] Of these, some are primarily up-to-date presentations of the general knowledge about the fundamental facts of visual sensation. Troland (129) has shown the importance of these data as the best established and organized that we possess in the field of psychology, and has emphasized the fact that the physical, physiological, and psychological conditions of the arousal of specific visual sensations are all deserving of investigation. Elsewhere (130), he has brought together conclusions concerning the fundamental facts in this field as established by various experiments, analyzing and systematically relating available data. A similar presentation of the basic facts has been written by Parsons(103). In a more exhaustive discussion, Tschermak(131) has brought together the facts concerning many particular aspects of sensations for which light is the adequate stimulus, giving a comprehensive digest of this material.

Piéron (106) has drawn upon data in the field of visual sensation in his consideration of fundamental laws of sensation in general. He concludes that the multiplicity of variables involved in sensory discrimination makes impossible the formulation of a general law of

[1] Only those articles published in English, French, or German have been listed. Some are included which appeared in the latter half of 1929, but it has been impossible to cover that period with any thoroughness.

relationship between stimulus and sensation of the Weber-Fechner type. He remarks that the Weber-Fechner law breaks down outside the middle range of intensities, and that it neglects to take into account the variations in response with different durations of stimulation. Reporting an experiment in which he found that the limiting duration of response to a particular intensity of illumination, as measured by the critical frequency of flicker, varies with a change in the relationship of the phase of stimulation to the phase of interruption, and increases with increase in the magnitude of interruption, Piéron (**108**) again indicates the insufficiency of our present formulations of facts. In his investigation of Talbot's law, however, he (**107**) finds that this particular law is valid not only for stimuli of relatively long duration where a certain sensation level is reached, but also for very brief stimuli, even for those below the threshold of fusion. Haschek (**55**), on the other hand, seems to consider it an established fact that Talbot's law fails when exposures are very short: 0.001 to 0.0001 second. He regards it as a merit of his photochemical, tri-color theory of vision that it explains this fact as well as color changes in chromatic adaptation, decrease in saturation with increase in intensity, and the Purkinje phenomenon.

Spencer (**122, 123, 124**) has investigated Heymans' law of inhibition and finds that his experimental results confirm Heymans' hypothesis. With binocular vision, the liminal value of a second light increases in direct proportion to the increase in intensity of the inhibiting light. When the test light is viewed by one eye, and the inhibiting light by the other, a similar effect of the inhibiting light was noted. This indicates that the inhibitory effect must be explained in terms of a central connection. The fact that the absolute threshold was found to be relatively high when the observer felt most "fresh," and low when he was more fatigued, indicates that "freshness," high organization of activities, and high coefficient of inhibition are found together; while fatigue is associated with disintegration and a low degree of inhibition.

Many other investigators have been concerned with phenomena more specifically limited to the field of vision. Cobb and Moss (**14**) have investigated the effect upon the visibility of stimuli of the four interacting factors: visual angle subtended, brightness level, brightness contrast, and duration of exposure. Curves of threshold visibility show variation of the liminal visual angle with per cent contrast, with three different illuminations of the ground, and for three different durations of exposure. A further study (**12**) indicates that

when one of these conditions fails to favor visibility, it can be compensated for by more favorable conditions in respect to some of the other variables. It appears that the optimal brightness for large, low-contrast objects is at a higher level than for small, high-contrast objects.

The decrease in visibility caused by the glare of a 100-watt frosted tungsten lamp placed in the vertical meridian above the fixation point was also tested by Cobb and Moss (15). The effect was scarcely appreciable by this test when the glare source was more than 10 degrees above the fixation point even when discomfort was experienced. Benford (5) has suggested that the muscular strain associated with the effort to accommodate for one point when a glare source tends to distract attention to another point is probably an important factor in the fatigue associated with glare. Stiles (126), investigating the effect of glare on the brightness difference threshold, found that the Fechner fraction suddenly increases when a background brightness of two candles per square foot is exceeded. Danjon (19) has discussed the part played by brightness and contrast in determining acuity. He finds that an empirical formula represents the variation in visual acuity as a function of brightness contrast between the test object and the ground, and of the least perceptible contrast at that brightness level. Variations from the relationship at higher illuminations are ascribed to glare effects and differences in pupil size.

Ferree and Rand (32) have shown how increase in intensity of illumination effects an increase in speed of discrimination. Details subtending visual angles of 1, 2, 3, 4, and 5 minutes were discriminated under illuminations varying from 5 to 100 foot-candles. It was noted that at 5 foot-candles, a black broken circle on a white ground was discriminated more quickly than a white broken circle on a black ground, although the reverse held at higher intensities. These facts are explained in terms of irradiation of the white ground and the masking effect of a white after-image on black. Varying effects of specular reflection under different conditions were also noted. Ferree and Rand (33) have also investigated the advantages to be derived from increasing the intensity of illumination, by determining the speed of discrimination at different illuminations of details of different sizes, and with different percentages of brightness contrast between object and background. They find that the gain in speed with increase in illumination is greater in general at low levels of illumination, when smaller details are to be discriminated, and

when brightness contrasts are low. Increase in the size of the object to be discriminated seemed to affect speed more than corresponding increase in illumination.

Hecht (**58**) has reviewed data on the variation of visual acuity with changes in intensity of illumination, and has showed that all are consistent with Koenig's explanation that the sigmoid form of the curve is due to the rods functioning at lower illuminations; the cones, functioning at higher illuminations, give a steeply rising curve which becomes horizontal when they reach their maximal activity. Hecht amends this explanation by postulating a statistical distribution of the functioning organs, taking into account the probable different thresholds of the individual rods and cones. With increase in illumination, it may be assumed that the thresholds of a larger number of sensitive elements are passed, and acuity is correspondingly improved. Hecht also finds in this data confirmation for his theory of a pseudo-reversible bimolecular photochemical process and for his calculations as to the minimal retinal area which must be stimulated if the absolute threshold is to be passed. Lasareff (**87**) also makes certain assumptions concerning the number of cones which must be stimulated to produce a liminal sensation when he deduces a formula from his quantum-ionic theory to represent the relation between the absolute brightness threshold and acuity as measured by the least distinguishable separation between two points. Experimental data showed agreement with the formula.

Freeman (**41, 42**) has found that under certain conditions the Aubert-Foerster phenomenon is reversed, and that under other conditions the relations between the sizes of test objects and the distances at which they are just visible are related in accordance with the laws of geometrical optics. Apparently the phenomenon is an artefact of method. When stimuli whose images fell in the periphery were illuminated for only 80 sigma with either white or colored light, objects subtending the same visual angles appeared equally visible. In the case of foveal perception, however, the ratios of threshold visibility were not proportional to actual size ratios when colored stimuli were used, and the ratios differed for different colors. Apropos of this observation, it may be mentioned that Pech (**105**) has recently reminded us that the properly corrected eye can only be emmetropic for the brightest part of the spectrum, and must necessarily be hyperopic for the longer wave-lengths and myopic for the shorter wave-lengths. Miles (**97**) describes the brilliant coloration of objects viewed through a prism held flat against the bridge of

the nose, and he observes that details are thus submerged and masses accentuated.

Bordier (7) explains how moire effects arise from the superposition of one mesh of parallel lines upon another. Since the phenomenon depends upon the presence of diffusion circles, it could not be observed by an eye with ideally perfect acuity. This same blurring at acute angles which is associated with slight imperfections of acuity makes the Maltese cross a sensitive test for astigmatism, according to Beach (4).

Discussion of photometric methods is of fundamental importance in relation to research in the field of vision. In a note of a page and a half, Smith (120) has pointed out the fact that although two photometric fields, A and B, may be equated and then, in a series of similar matches, substitution may be made alternately on one side and then the other so that the series is of the order: A=B, B=C, C=D, . . . . ., it is nonsense to suppose that A will equal the last term of the series in hue and brightness. Campbell (11), in answer, points out that "equality" in measurement is not a transitive relation, and remarks that, although the theoretical difficulty might not be recognized, no one would, in practice, use such a photometric method as the one described. Richardson (113) answered the same note with a reminder that the range within which equality is judged to be such varies with a second stimulus when the first is kept fixed.

Crittenden and Taylor (18, 127) have sponsored an ambitious project in the endeavor to standardize methods of heterochromatic photometry. Six laboratories co-operated by measuring thirteen colored filters whose integral transmissions had been calculated from spectrophotometric measurements and standard visibility data. Although this method yields best agreement, it was hoped that the interlaboratory comparison would justify the general adoption of some more simple and feasible means of measurement. It was found that averages of determinations made by the equality of brightness method approached those found by spectrophotometry but results could not be considered conclusive, especially since observations made with different photometer heads gave varying determinations even for the same group of observers. When the flicker method was used, certain systematic differences appear in the determinations made by different laboratories. These differences showed no correlations with individual differences in color sensitivity as tested by the Ives' solutions. It seems not unreasonable to hope that the sources of these

systematic differences may be discovered. At present, results scarcely justify a preference for either of the substitute methods.

The question of the optimal fields for photometric comparisons seems to have inspired the interest which Heinz and Lippay (**61, 62**) have shown in the relation between ability to discriminate and magnitude of the retinal area stimulated. They find that discrimination improves with increase in the size of the image, but not regularly. At the macula, there was an increase of more than 100 per cent in discriminability between fields subtending respectively 0.15 and 0.26 mm.; in the periphery of the retina, the same increase in field produced nearly three times that increase. The authors conclude that within limits, the observer's ability to discriminate is a function of the number of sensory elements excited. Martin and Richards (**93**), working with a black object exposed on a light ground, studied the effect of varying the brightness of the surrounding field in order to determine the optimal size of surrounding field in binoculars. They found that a smaller field was advantageous when the field was brighter than the ground; a larger field when it was darker. Cobb and Moss (**13**) devised an experiment to determine the effect of a dark surrounding field when the observer was concerned with a lighted area of varied dimensions. Performance was found to be more accurate when the lighted field subtended an angle of 9 degrees or more but there was little further gain when the angle subtended was increased beyond 16 degrees. Löhle (**89**) has been interested in the relations between magnification, and extent and brightness of field as determinants of the efficiency of telescopes used in making observations at low illuminations. He concludes that the efficiency of telescopes having equal objective openings increases as the square root of the magnification; with equal magnification, efficiency increases as the square root of the area of the entrance pupil. This accords with his observation that twilight acuity depends upon brightness contrasts. However, Kühl (**85**) finds quite unacceptable Löhle's suggestion that discrimination varies with the square root of the subjective intensity of illumination. He offers a formula in which acuity is shown to be a function of the logarithm of the intensity of illumination. This seems to fit both Löhle's data and his own, and also mediates the transition between Riccò's and Piper's laws. In a more recent article, Löhle (**90**) reports data showing that when threshold intensity values were determined for two observers, Piper's law was found to hold for angles from two to seven degrees,

while Riccò's law holds for angles up to ten minutes both for foveal and extra-foveal vision.

Differences in the functioning of different parts of the retina have been the subject of a number of studies. Weymouth and his colleagues (135) found a uniform decrease in sensitivity from the fovea centralis to the periphery. No differences were found which could be associated with the anatomical peculiarities of the fovea centralis, rod-free area, macula, or non-vascular area. The decrease in sensitivity is more rapid in the vertical than in the horizontal meridian. Kleitman and Piéron (76), investigating differences in the rate of superfiicial summation of light impressions by determining the least perceptible brightnesses of four circles subtending angles varying from 6 minutes 10 seconds to 61 minutes 40 seconds, found that the rate of superficial summation increases as these surfaces are farther from the fixation point. At 60 degrees, under conditions of both light and dark adaptation, summation is practically integral; at the fovea, negligible. Particularly in light adaptation, absolute sensibility increases on approach to the para-foveal region. Results were the same for white and for green light. For red light, in light adaptation, summation was practically integral except for the region within 10 degrees of the fovea; in dark adaptation, summation in the para-foveal region was greater than for other lights but less than the summation for red under light adaptation.

Ferree (31) shows how the higher critical frequency in the periphery as compared with the center of the retina explains a phenomenon reported by Gradle (51) and amplified by Gaehr and Packard (44). The former had noted that the rotating propeller of an aeroplane was invisible, or a blur, when viewed directly, but that the rotating sectors are visible with eccentric fixation.

Renquist and Malin (110) rotated screens of complementary colors, red or yellow before one eye and green or blue before the other, and then timed the duration of rivalry with dark and with light adaptation, with central and peripheral observation, and with fields subtending visual angles of 2, 4.5, and 13.5 degrees. Rivalry persisted longer in all cases for light adaptation, and for the center as compared with the periphery. For the 2 degree field it endured longest, but for the 4.5 degree field it ceased more quickly than for the 13.5 degree field. The writers ascribe this fact to the inhibiting effect of the rods upon the functioning cones, which latter they conclude are responsible for the persistence of binocular rivalry. The relative absence of this phenomenon in the periphery is also ac-

counted for in terms of functional advantage: differences in peripheral images are frequent under normal conditions and must be ignored, hence any tendency to rivalry would be inhibited.

Creed and Granit (17) have measured the latency of negative after-images after 15 seconds' fixation. They find a maximal latent time at the fovea, decreasing regularly to about 2 degrees excentric, rising to a new maximum between 2 and 3 degrees, with another steady decrease following. They associate the second maximum with the replacement of the cones by the rods as the dominant functioning organs. They find, also, that the latent time depends on the latent time for that part of the retina where the margin of the disc falls, the rest of the image immediately filling in in a fashion analogous to the supposed filling-in of the blind spot. It may be noted here, however, that Helson (63) has undertaken to upset some of the familiar theories about the blind-spot, and offers experimental evidence for his view that the blind-spot is in some degree sensitive to light stimuli.

Kleitman and Blier (75) have studied color and form discrimination in the periphery. When they investigated the limits at which each color could be recognized with certainty by moving one of six colors in from the periphery until the observer identified it, the blue field appeared to be largest, white and red about equal, yellow, green, and gray smaller and approximately equal. But it was shown that the possibilities of confusion influenced the determinations, for the limits were increased and white became about equal to blue when the last three colors were eliminated from the test. Yellow also showed a larger field when the test was made with only red, yellow, and blue. When the form sense was similarly tested with circles, triangles, squares, and five-pointed stars each of five different sizes, it was found that discriminability varies as the size but shows no significant differences for the different figures. The unequal decrease in sensitivity from the fovea outward in different meridians was noted. Fazakas (29) investigated the chromatic sensitivity of the peripheral retina by determining the locations of the thresholds for colored circles of various dimensions on a black ground. At any given point, sensitivity appears to be greatest for red and yellow, less for green, and least for blue. Isopters are elliptical and parallel, and about equidistant for each one minute increase in the diameter of the test object from 10 degrees to 65 degrees on the nasal side. Fazakas points out some inadequacies of the duplicity theory and suggests that the greater sensitivity of the nasal part of the retina

may be due to its greater functional importance. Ferree and Rand (34) find that color fields mapped with red, blue, and green Heidelberg pigments on neutral gray, are less extensive than the form fields and show a greater range of variation for different individuals. Individual differences in color sensitivity and the greater effect of the judgment factor account for the latter fact. For the different colors, the average meridians were, in descending order, white, blue, red, and green. When the range of individual variations was considered in relation to sex, age, and refraction (35), it appeared that sex differences are not significant, and that age does not appear to be a factor below forty years. Fields of myopes and presbyopes ranged smaller than those of emmetropes and hyperopes. Gaudissart (46), following the suggestion that colored stimuli give smaller fields than white of the same size, presents data showing how this reduction in fields is effected either by reducing the size of the white or by substituting colored stimuli.

Adams' (1) comprehensive review of the literature on dark adaptation considered in all of its phases has been announced in several reviews as indispensable to anyone interested in related problems. The material is organized so as to furnish a ready guide to particular aspects of phenomena of dark adaptation. Some seven hundred titles are included.

Møller (98) has used Tscherning's photometric glasses in investigating phenomena of dark adaptation. He determined the apparent brightness of an object by comparing it with a surface of constant size and illumination which could just be seen through the densest glass after maximal adaptation, using as a measure the glass necessary to effect apparent equality. All of the adaptation curves which he plotted from his data show a regular rise, without any transitions such as the author claims would be expected if two different factors, such as different rod and cone functions, were involved. He finds that the time required for dark adaptation after exposure to a given light is the same as that required for "disadaptation," *i.e.*, for reaching the original state of light adaptation. He finds no binocular summation of stimuli, and claims that the two eyes adapt independently. For maximal adaptation, the visibility of objects of moderate size is found to be a function of brightness and area,—the area of the retinal image and of the threshold brightness yielding a constant product. Red adaptation is difficult to demonstrate except under optimal conditions. Møller finds that when red is no longer visible, a central scotoma is also present. He associates

this relationship with absorption of the short wave-lengths by the macular pigment. Since the red rays are not visible, and the short wave lengths are absorbed, the sensitive elements of the macula are not stimulated. He also explains the reversal of the Purkinje phenomenon in the fovea at low illumination as due to the macular pigmentation, not to the absence of rods. He demonstrated peripheral adaptation by means of an acuity test and also showed the decrease in acuity with decreasing illumination. All measurements are expressed in units representing the Tscherning glasses used in making the determinations. Edmund (26) used the Tscherning glasses in investigating the duration of luminous impressions under different conditions of adaptation. An ingenious method of measurement showed that the impression lasted 0.03 second longer for each reduction of brightness by one photoptry, *i.e.*, with use of the next denser glass.

In their study of the effect of dark adaptation on the critical frequency of flicker for different illuminations, Lythgoe and Tansley (92)[2] found a fall in the critical frequency at the fovea during the first ten minutes or so of adaptation, while in the periphery there was a fall with high illumination of the test patch and a rise for low illuminations. The fall is attributed to the dark adaptation of the cones; the rise, to the rods. When the brightness of the surrounding field was progressively decreased, the results showed a similarity to those obtained during prolonged dark adaptation. The authors conclude that a mild dark adaptation is induced by a decrease in the illumination of the surrounding field, while an increase causes a corresponding light adaptation.

Heinemann (60) reports a study of the differences between momentary adaptation and adaptation after prolonged exposure. Subjects were adapted to a given intensity and then the experimenter recorded the time which they required for recognition of a stimulus of 1/300, 1/600, or 1/1200 the brightness of the light to which they were adapted. He found that this period increased with longer adaptation to the first light, and with decrease in the relative brightness of the test light. It was shorter for the moving eye than for the fixating eye, and shorter with binocular than with monocular vision. Children were slower than adults to adapt to high illuminations, but adapted to low illuminations more quickly. Children adapted more quickly than adults to green and blue; more slowly to

[2] Adams' (1) review of this article is the source of the comments upon it made here.

red. Apparently the Purkinje phenomenon is more marked in youth. Heinemann suggests taking as a quantitative measure of the Purkinje phenomenon the ratio of the brightness of the blue to the brightness of the red which requires the same time for adaptation. He explains his observations in terms of Müller's theory of the inhibiting effect of the functioning cones upon the rods.

Lasareff (**88**) presents data showing that the sensitivity of the dark adapted eye is low in childhood, increasing to a maximum at about eighteen years of age, and then gradually decreasing until at the age of eighty, only about 25 per cent of the maximal sensitivity is retained. He shows that this empirical data is in satisfactory agreement with the sensitivities calculated from a formula derived from his theory that there must be a constant concentration of a hypothetical sensitizing substance to maintain function in the nerve cell and hat this substance is present in different amounts at different ages, so that only a portion of the nerve cells present are capable of functioning in very early and very late life.

Siegfried (**117**) claims to have disproved the alleged harmful effect of ultra-violet rays on adaptation by showing that with equal periods of exposure, a 50 candle-power light with the ultra-violet rays cut out impairs adaptation more than the concentrated ultra-violet rays of a Bach lamp.

Parsons'(**104**) casual remark that the eye is adapted to utilize the rays in the region of the maximum of the sun's emission has been criticized by Smith (**121**) who points out that when the curve of emission is plotted in terms of frequency rather than of wave-length this fact does not appear to be true. Hartridge (**54**), in opposition to Smith, claims that there are no adequate grounds for regarding frequency as more significant than wave-length. Pokrowski (**109**) offers another explanation for the lack of coincidence between the sensitivity curve of the eye and the curve of energy emission of the sun in the region of the visible spectrum. He suggests that the eye developed under conditions where not direct sunlight, but light reflected from the green grass and leaves determined the course of development. The sensitivity curve fits in very well with this hypothesis. Hauser (**56**) has claimed priority for this suggestion, since he had suggested earlier that the differences between peripheral and foveal visibility curves are due to the influence of vegetation in affecting the intensity distribution of the effective light of the sun.

Parsons'(**104**) reference to rods as the organs of twilight vision

and to cones as functioning in photopic vision has been criticized by Forbes (37), who maintains that this is no longer obvious. The presence of color sensitivity in the middle range of adaptation where the rod function must be assumed to be dominant, seems to indicate that there is some photochemical substance involved whose distribution is not necessarily coincident with that of rods or cones. Edridge-Green (27) also took the occasion of Parsons' brief article to criticize the current version of the duplicity theory, offering his own explanation that the rods are not percipient elements but control the visual purple which in turn sensitizes a photo-chemical substance surrounding the cones, and stimulating them as it decomposes.

In discussing the Purkinje phenomenon, Jaensch and Stallman (67) present a different type of explanation. They undertook to determine whether the presence of different levels of experience can be demonstrated in the sensory realm. They concluded that a disintegration of the more developed functions, and a reversion to a lower level of experience is apparent in vision when observers are fatigued. The change in brightness values represented in the Purkinje phenomenon are considered to occur at this lower level of functioning, for the Purkinje phenomenon is absent when accurate discrimination, involving the later developed functions, is required. The Purkinje phenomenon, then, is considered by these authors to represent the dominating activity of the primordial functions and the relative inactivity of the later developed functions. Jaensch (66) also suggests that the Purkinje phenomenon may have a teleological explanation, since Rayleigh has shown that night light contains a larger proportion of short wave-lengths than daylight, and consequently the dark adapted eye is better prepared to make the best use of this changed distribution of the components of natural light. He finds this functional explanation quite consistent with the duplicity theory, although he is inclined to believe that twilight vision represents a more extensive system of functions than mere rod vision.

Gross (52) employed various methods in establishing his conclusion that the Purkinje phenomenon is absent at the fovea. He found that when he used Vogelsang's method of *Momentadaptation,* it was very difficult to maintain fixation, and he attributes Vogelsang's contrary results to failure in this respect. Gross found that the area in which the Purkinje phenomenon appeared to be absent corresponds very well with the rod-free area. He suggests that several two-factor theories may account for his conclusions: von Kries' duplicity theory; Tschermak's modification of the Hering theory; absence of

visual purple in the rod-free area; different concentrations under different conditions of adaptation of two photochemical substances of different absorption curves.

A posthumous report of an experiment by Broer (8) indicates that the Purkinje phenomenon is independent of dark adaptation. Using stimuli which, exposed together under conditions of light adaptation, gave after-images of red and blue of equal brightness, Broer found that a Purkinje phenomenon appeared when these were observed projected on a light screen in a dark room, although the observer was not dark adapted. Rosenberg (115) has investigated the range of illumination at which the Purkinje phenomenon is apparent in different regions of the retina. He concludes that within these limits the rods and cones function together, while below the lower limits, about 1/80 lux, the rods apparently function alone; the cones functioning alone above the upper limits of the Purkinje phenomenon. He found no evidence of this phenomenon at the fovea, but it was found with the stimulus three degrees excentric, and continued at higher illuminations as the stimulus was moved further into the peripheral field.

Sloan (118) has investigated the Purkinje phenomenon by studying the changes of the visibility curve with systematic variations in intensity of light, size of photometric field, and state of adaptation of the eye, making determinations for twelve spectral wave-lengths. She used a method of heterochromatic photometry, exposing the test field for two seconds. The point of maximum visibility was found to shift only below an intensity of 0.2 meter-candle. The Purkinje effect was always apparent on a change from light to dark adaptation when other variables were kept constant. Decrease in size of field increased relative sensitivity to short wave-lengths except under conditions of dark adaptation at low intensities, when the effect was reversed.

Several experiments are reported which have to do with phenomena of chromatic adaptation. Almack (2) has measured the loss of sensitivity to spectral red, yellow, green, and blue lights, equated in brightness, in saturation, and in energy, after stimulation for periods between 2 and 300 seconds, under conditions of light and of dark adaptation. By systematically varying the conditions, she has shown the effects of the four variables involved: wave-length, intensity, and duration of stimuli, and state of adaptation of the eye. Almack finds that the loss in sensitivity is greater as the original sensitivity of the unfatigued eye is higher. She regards saturation

and brightness as effective factors only as they are functions of intensity. She suggests that the curve for chromatic adaptation represents the arousal of some complementary process, since subliminal stimuli are sensed first as of the complementary color, at higher intensities as colorless, and finally as of their actual hue.

Gasteiger (45) plotted dark adaptation curves after twenty minutes pre-exposure to spectral red, orange, green, and blue of equal physical intensities. He found that initial sensitivity was highest after adaptation to red, lowest after adaptation to blue, with orange and green intermediate. Since the subjective brightness of red was appreciably greater than that of blue, subjective brightness apparently was not a factor. Gasteiger concludes that the cones must play a part in dark adaptation, since only they show differential response to different wave-lengths.

Comparing his data on the course of brightness decrease in chromatic adaptation to spectral lights with the implications of Lasareff's theory, Kravkov (81) finds that these data support the theory, yielding exponential curves with the exponents showing a linear increase with increase in the intensity of the stimulus. The curves differ for the three different wave-lengths used; violet was more fatiguing than red, red more fatiguing than green.

A different aspect of brightness relationships has interested Hiecke (64). He offers a formula for calculating the brightness of a mixture of monochromatic lights. The chemical law of mass effect affords him an explanation, by analogy, of the fact that a mixture of red and green lights never has a brightness value equal to the sum of the separate brightnesses of the component lights.

Stainton (125) has investigated the phenomenon of Broca and Sulzer. He had observers adjust the brightness of a standard field until a photometric match was obtained with a flash enduring through varying fractions of a second. The subjective brightness of the accurately timed test stimulus was measured in terms of the objective standard seen as equal. Stainton concludes that the rise of sensation is primarily a function of intensity, and shows little variation when different spectral lights and white are used as stimuli.

Lowry (91) has investigated the differences in brightness sensitivity with binocular and monocular vision. He found that contrast sensibility is much greater with binocular vision when the observation is made at a brightness level of below 50 milli-lamberts, but that binocular and monocular vision give more nearly equal results above this level. By using an inverse method of threshold determination,

Lowry again demonstrated the greater sensitivity with binocular vision, especially with low illuminations of the surrounding field. Zigler and Ward (**138**) found phenomenal differences between uniocular and binocular vision similar to those reported earlier by Katz: uniocular vision gives rise to an impression of lesser brightness, indefinite localization, increased distance, reduction of hard surface characteristics, and it reduces the tendency toward objective reference.

Fedorow and Fedorowa (**30**) find that brightness curves plotted from measurements made after stimulation by intense red or green spectral light resemble those of protanopes and deuteranopes. They suggest that their method might be applied to the investigation of the normal sensation curves for red, blue, and green, since it seems that a temporary color-blindness can be induced in a limited retinal area. They plotted their curves by comparing the brightnesses of neighboring points at equal intervals throughout the spectrum. They explain a quirk in the curve in the blue as due to macular pigmentation and fluorescence of the ocular media in the blue and violet. A redetermination of the tri-chromatic coefficients of the spectral colors has been undertaken by Wright (**137**). Ten observers took part in the experiment, each making about thirty matches throughout the spectrum after five to ten minutes dark adaptation. Wright attempted to eliminate individual differences by having observers match the three selected colors to monochromatic lights. In this way he determined factors for correcting for individual differences.

Fatigue induced by stimulation by white light of three widely different intensities during periods varying from five seconds to two minutes, has been measured by Geldard (**47**). Fatigue effect is plotted in terms of the percentage of illumination of comparison light required for a match as compared with that required for a match before fatiguing. With more intense stimulation, curves fell more steeply in the first twenty seconds and reached a lower lever,—*i.e.*, less light was required from the comparison light to effect a match. A further study (**48**) showed that the fatigue of a limited area of the retina effects an increase in sensitivity in adjoining areas, since more light was required for a match when the fatiguing light was observed by one eye, the test light by the other. Geldard's apparatus was used by Johannsen (**68**) in a study of recovery from visual fatigue. She found that recovery is a function of the duration and intensity of the original stimulation, and is much quicker for some observers than for others. Wirth (**136**) suggests that certain differences in sensitivity may be measured by investigating

the relative effects of after-images immediately following brief fixation. He determined the objective brightness difference necessary to maintain subjective equality between the red and green halves of a circle after five seconds' fixation, and also determined what effect was produced in the apparent saturation of one color after five seconds' fatigue to its complementary. Measurements are given in terms of the percentage of contrast color which must be added to the original color when it is observed after five seconds' observation of its complementary, if it is not to appear more saturated than the same color observed without such previous stimulation.

A number of other investigations have also been reported concerning the after-effects of stimulation as represented in after-images. Warren (**134**) recounts an experience in which a vivid after-image appeared after an intervening sleep of ten to fifteen minutes. The image underwent changes which duplicated the course of the original experience. Burridge (**10**) extends to after-images his explanation that functional changes persisting after removal of the excitants may be due to mediation of the excitability by processes of colloidal aggregation which develop at variable speed and subside in their own time. Frehafer (**43**) has acted upon Forbes'(**39**) suggestion that the merits of proposed standard whites might be investigated by observation of the first after-image, in which there appears, under favorable conditions, a flash of color of higher saturation than that of the original stimulus. She varied the color temperature of a standard light source by means of a rheostat, but found no point at which the after-image consistently appeared colorless. She found that this after-image failed to appear at the fovea centralis.

Judd (**69**) has suggested that the Purkinje phase of after-images, as well as the blue arcs of the retina, may be due to visible radiations from active nerve fibers. Using spectral lights of different wavelengths as stimuli, Judd found that there is a definite rise in intensity of stimulus necessary to evoke the blue arcs with increase in wavelength of the stimuli. He is inclined to believe that at low illuminations, the blue arcs are consequent upon activity initiated by the rods. In the main, of course, Judd is following Ladd-Franklin's suggestion (**86**) that the blue arcs are due to luminosity of the excited nerve fibers. Ellis (**28**) found no evidence for this view when he stimulated frogs' retinae electrically. He concluded that the objections presented to the alternative electric theory of causation are not cogent, and he shows how this theory is competent to explain the observed after-images of the blue arcs.

In a series of three papers, Ebbecke (23, 24, 25) presents conclusions based on his repetition and extension of experiments with after-images. He suggests that the brightness of background against which an after-image just disappears may be taken as a measure of the strength of the image. With suitable projection fields he has succeeded in showing that positive and negative after-images endure equally long. Emphasizing the necessity of distinguishing between duration of visible images and duration of physiological after-effects of stimulation, Ebbecke cites evidence indicating that the latter endure so long that permanent scotomata induced by exposure to direct sunlight may be regarded as limiting cases of this phenomenon. The disappearance of the observable image is explained as due to adaptation. The second paper describes the *positives Hellbild* which Ebbecke observed when the background was brightened suddenly. He explains this phenomenon of a positive after-image appearing on a bright projection field in terms of the supposed enduring effect of stimulation and the antagonistic adaptation process which he assumes must be occurring somewhere in the nerve pathway. This same hypothetical antagonism is offered as explanation of the spontaneous fluctuations in the after-image: a positive after-image would be present when the retinal after-effects of stimulation are the dominating factors in the experience; a negative image, when the adaptation processes occurring at a higher level are in the ascendency.

Phenomena observed in studying rivalry in after-images has demonstrated, according to Gellhorn (49) that concurrent or previous stimulation of one eye affects the other through some intracortical process. He found rivalry more pronounced when the stimuli for the two eyes showed marked differences in intensity or hue. That color dominates which contrasts most with the brightness of the background. Twenty seconds' fixation appeared most favorable for the appearance of rivalry. The gestalt factor failed to influence rivalry in the after-images. When the projection screen was observed monocularly after fixation under conditions favoring the appearance of binocular rivalry, the phenomenon appeared. The image of the observing eye tended to dominate except when the factor of brightness contrast was employed to favor the dominance of the image of the non-observing eye; by this means the latter image could be made to dominate.

Karwoski (70) has found that after-images following stimulation by spectral lights of various selected wave-lengths show characteristic variations in hue with changes in the intensity of the stimuli.

Only at moderate intensities was the hue of the complementary favored; at higher intensities, purplish hues appeared. Karwoski offers the explanation that above moderate intensities, subsidiary processes are aroused in relative disproportion, the dominant process having already reached its maximum. Consequently, after-images from stimuli of high intensities show hues complementary to those associated with these subsidiary processes.

Problems associated specifically with color vision are numerous enough, and sufficiently productive of controversial discussion, to claim a literature of their own. Omitting studies of anomalous color vision and color vision in animals, there remains a body of literature almost equalling that which has been reviewed above as referring to all of the other aspects of the specifically sensational aspects of vision. Andrade (3) is the author of a simple exposition of the fundamental facts of color vision and color measurement. A book by Hillebrand (65), published since his death with emendations by his wife and former student, presents a fuller exposition under the headings: I, the dependence of color sensation on stimulus; II, the dependence of color sensation on sensitivity; III, color theories. In the last section, Hillebrand has pointed out the advantages and defects of both the Young-Helmholtz and the Hering theories. Tschermak (132), on the other hand, shows a decided preference for the four-color theory, emphasizing its more adequate explanation of certain facts where the tri-color theory is generally admitted to fail. He admits the necessity of extending and modifying the present four-color theory, however, suggesting that a distinction between receptor organs and conducting apparatus with different influences attributed to each, would help to explain variations under different conditions of adaptation, the independent variations of brightness and color changes in after-images, and other phenomena which now present difficulties for this favored theory. Ladd-Franklin's (86) published work on color theory has been republished in book form with a few emendations and together with some discussions by other writers. A criticism of the Ladd-Franklin theory is offered by Müller (99), who remarks that Mrs. Franklin's request for his opinion has finally persuaded him to publish his objections. These are presented under six headings, and as briefly as is consistent with clearness. Birren (6) and de Gourmont (20) are authors of recently published books having to do with color phenomena, but I have found neither the original articles nor reviews available.

The position of gray in the color pyramid has been discussed by

Dimmick (21) and by Dimmick and Holt (22). Dimmick warns against allowing physical and physiological consideration too much influence in determining the psychological conception of the color pyramid. He calls for due consideration of the psychological uniqueness of red, green, blue, yellow, white, black, and gray; and of the fact that in experience hue, brightness, and saturation do not vary independently. He criticizes two recent theories proposed by Rich and Forbes. In answer to a criticism of their earlier report on the relation of gray to black and white, Dimmick and Holt carried through an experiment designed to force unitiated observers to develop color categories of their own by requiring them to recognize color changes due to varying proportions in mixtures. Observers tended to drop out orange and purple and to include gray as they became more proficient, and all found it necessary and sufficient to include as unique categories red, yellow, green, blue, black, white, and gray. Gertz (50), extending the mechanical analogy of the color triangle, suggests that the arousal of a white sensation by the compounding of conditions for the arousal of various color sensations may be compared to the transformation of different forms of energy into heat. He would regard white as being the lowest form of vision and so would explain the frequent retention of achromatic vision when chromatic vision is pathologically destroyed. Österreich (101) describes a number of demonstrations of the fact that mixing yellow and black gives rise to a sensation of green. He regards it as an evidence of the inadequacy of color triangles and other schemes representing color relationships that they fail to indicate this phenomenon. Kiesow (74) has answered this contention by maintaining that this green is a product of psychic synthesis. Apparently he claims that a mixture of yellow with black or gray gives brown.

In a communication to the Academy of Sciences, Ostwald (102) has expressed his views on the fundamentals of chromatic measurement. Matthaei (94, 95) has used the colors in the Ostwald color circles in his experimental attempts to study hue differences in isolation from subsidiary attributes. In the first part of his paper, Matthaei explains how his measurements of the brightnesses of the different colors in the Ostwald circle indicates that the circle includes three groups of colors of different brightnesses. He concludes that the apparent brightness values of colors under dark adaptation is a function of cortical processes. In constructing a color body from the color circle, Matthaei makes the brightness attribute the ordering principle. Nyberg's (100) scheme for construction of a pigment

color solid is made without reference to any physiological hypothesis. A critical review of Ostwald's color theory, based upon mathematical grounds, opens the way for the new theory which Nyberg presents.

Schubert (116) has demonstrated the weakness of one major point in the Ladd-Franklin theory, by showing that under conditions of neutral adaptation, suitably chosen spectral red and green mix to give a colorless light. The validity of the judgment was established by Herings' method of successive contrast, and by equation with another binary mixture itself verified by the Hering method. Schubert found characteristic differences in color sensitivity among different observers, and different color tones appeared in duplicated mixtures under slightly different conditions of light adaptation. Light adaptation at different times of day, and under different circumstances of brightness or cloudiness, gave rise to different judgments.

Hecht (57) describes an easy method of producing binocular fusions of colors. He concludes that the uniformity with which his observers reported the appearance of yellow when they had a red filter before one eye and a green filter before the other, shows that the fusion of these colors to produce yellow must occur at some higher level than in the retina. He regards this demonstration as a further vindication of the tri-color theory. Rochat (114) claims to have demonstrated the subjectivity of contrast colors by showing that appropriate selection of the surrounding field may give rise to the appearance of a contrast color in a gray field illuminated by a mixture of monochromatic complementaries when the induced color does not enter into the composition of the gray field. The same contrast color appears when the neutral field is illuminated by a mixture of monochromatic lights and when it is illuminated by natural white light. Focht (36) explains her contrary observation that color contrast is absent except when white light is present, as evidence for the view that the contrast effect is due to the failure of a lesser stimulus to evoke response when a stronger stimulus is present. For instance, when white is presented in a green field, the green component in the white fails to arouse response and consequently the white takes on a reddish tinge, according to her explanation.

Van Heuven (133) has investigated the effects of simultaneous contrast for different colors under different conditions of illumination and for different degrees of saturation, by measuring the inhibition of objectively measured irradiation effects. He found that irradiation phenomena stand out best in white light, less in blue and green. Although these values do not hold for subjective judgments, here

again red values are least. Simultaneous contrast values are found to be less for colored than for white light, also differing less for different intensities. Following up his own demonstration that chromatic adaptation proceeds at different rates for the three basic colors of the Young-Helmholtz theory, Kravkov (**83**) explains his observation that there seems to be a disproportionate impression of red present in cases of successive contrast as due to the unequal rates of fatigue to the different components in the original experience. The successive contrast colors he would regard as complementary, not to the original stimulus, but to the color-tone which this assumes after chromatic adaptation. Tennant (**128**) warns against the disregard of the higher cerebral processes in explaining facts of color contrast. He points out the part played by fatigue due to long fixation, and the influence of perception of the total situation, the differences between absolute and comparative judgments, and the possible effect of suggestion. He indicates the inadequacies of both Helmholtz' and Hering's views, and emphasizes the necessity of taking account both of physiological retinal processes and of higher cerebral processes.

Collins (**16**) finds that the Rayleigh color equation, derived by mixing spectral lights, is also valid for mixtures produced by rotating pigment discs, and equated with yellow, blue, and white. The results of two hundred observers were used to establish her conclusions. The difficulties of judging the proportions of the different components in a mixed color are indicated in the work of Richardson (**112**) and Maxwell (**96**), who asked observers to indicate their estimates of the redness of different pinks by giving them places on a scale in which 0 represented white and 100 represented scarlet. Experience and exposure sequence seemed to influence judgments. Maxwell claims that he found some correlation between estimated value and per cent angle of red in the rotating discs.

Several German investigators are concerned with the problems of *Farbentransformation, Kontrast,* and *Helligkeitskonstanz.* Kravkov (**82**) claims that the action of a central process, effecting a compensatory response, must be invoked to explain the observation that a white surface brightly illuminated by a colored light appears less colored than the physical conditions would lead one to expect, while objects similarly illuminated undergo color changes such as would result from an admixture of the color complementary to that of the illuminating light. Haack (**53**) discusses the question of the identity of color transformation and contrast effects. She submits

the argument that phenomena of contrast are almost completely independent of intensity of illumination, while phenomena of transformation show a regular variation with changes in intensity of illumination, as evidence of the independence of the two phenomena. She seems inclined to adopt Katz' view that simultaneous contrast is peripherally conditioned; transformation being due to central factors. Kravkov and Paulsen-Bachmakowa (**84**) find that color changes due to illumination by colored light do not induce a contrast effect. This again indicates that there is an essential difference between contrast and color transformation. Katona (**71**), investigating the relation between experience and the apparent brightness of objects under different illuminations, finds that familiarity with objects favors *Helligkeitskonstanz* but is not a *sine qua non* of that phenomenon. The phenomenon is only present, however, when different illuminations or different objects under the same illumination make comparisons possible.

An article by Krauss (**79**) is the one first selected for criticism by Katz in his *Sammelreferat* (**72, 73**) on reports of research concerned with perception of color. This review represents really a series of searching criticisms of work reported within the past three years by Krauss, Bocksch, Ehler, Friedler, Granit, Kardos, and Brunswick. Only the work of Ehler and of Brunswick win even qualified approval from Katz. Krauss (**80**) has replied to Katz' criticism with the reminder that Katz neglected to consider several points which Krauss had regarded as of especial importance in the original work, but Katz denied, in turn, that Krauss' answer in any way detracted from the significance of his criticism.

A phenomenal study of relations of transparency, form and color has been made by Tudor-Hart under the direction of Koffka (**77**). She measured the effect upon the appearance of yellow circles viewed through a blue episcotister, of exposing a gradually increased number of similar circles outside the field of the episkotister, by measuring the decrease in the opening of the episcotister which was necessary to make the circles appear a neutral gray, as they did when no yellow circles were freely exposed. She also investigated the apparent transparency of the episcotister with relation to its brightness differences from a varied background. Mintz (**78**) has also contributed a study on brightness effects undertaken under Koffka's direction. He concludes that Weber's law may hold under very simple conditions, but that many other factors than intensity of stimulus contribute to recognition of differences in brightness. Using the same brightness

in different constellations, he finds support for the contention that effects must be explained in terms of the total stimulus situation. Brown and Hoisington (9) report a study in which observers reported the apparent presence of color in a surface exposed through an opening in a uniformly illuminated screen. The exposed color was varied through five brightness steps. Two observers showed a tendency to report color whenever there was a brightness difference present. Light colors were reported more frequently when the test spot was brighter than the screen; red, green or blue were reported when the spot was darker.

Several writers are endeavoring to supply the recognized deficiencies of the classical theories of color vision by offering new hypotheses. Rich (111) offers an eclectic theory, modeled after the Ladd-Franklin theory, but making gray the center of the visual system and black and white a disappearing pair. He postulates a primitive color molecule which mediates gray, and which differentiates with respect to intensity into a portion which responds to all wave-lengths and mediates white, and another portion which, upon spontaneous decomposition, mediates black. The former differentiates into processes mediating respectively blue and yellow, and the latter of these differentiates into processes mediating red and green. Phenomena of contrast and after-images are explained as due to spontaneous decomposition of the split products.

Hecht (59) has undertaken to express certain fundamental facts of vision in formulae. He has shown how they can be explained on the assumption that there is a photosensitive substance which decomposes in the light to form two products, which recombine, under dark adaptation, to form the original substance. He recognizes certain over-simplifications involved in this analysis, and suggests some necessary amplifications of the theory as thus outlined. In discussing color vision, Hecht emphasizes the advantages of the tri-color theory and suggests that three types of cones be postulated to account for the differential responses to the three fundamental colors.

Forbes (40) has analyzed the data for the visibility curve as determined under different conditions by Koenig, Ives, Sloan et al., in an effort to discover what factors must be assumed to play a part in the appearance of the Purkinje phenomenon. He finds evidence for the existence of three or four component processes: two or three photopic; the last, scotopic. Although the data are not conclusive, results arrived at by the different observers all show fair agreement with Forbes' tentative explanation. A more elaborate theory which

Forbes (**38**) suggested earlier, represents an attempt to meet the objections raised to previous theories and to take account of all familiar facts of color vision, adaptation, after-images, etc., without postulating processes or structures which are not at least analogous to those already known to exist in the organism. Forbes postulated a " visual violet," analogous to the visual purple, but with a different absorption curve and probably present in relatively minute amount. He postulated three different types of cones: a white, a red, and a yellow. Black, green, and blue stimuli he considered inhibitory in their action. The nature of the response is explained as a function of the interference of incident and reflected rays in one of the two critically different parts of the cones, found on either side of a dividing membrane, according to the hypothesis. The acid reaction associated with the bleaching of the visual substance on that side of the membrane where maximal interference occurs, determines whether the region nearer the nerve fiber shall be relatively acid or basic, and, consequently, whether an effect of stimulation or of inhibition shall be apparent. Forbes develops some implications of this theory.

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# RECENT RESEARCH IN THE FIELD OF AUDITION

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A considerable amount of interest still appears to be shown in the experimental work carried on among psychologists and their kinsmen in the neighboring fields of physiology, pathology, physics and electrical engineering. So strong is this interest and so productive are the experimental researches that the reviewer is sure of the increased returns which would accrue if some central organization for the exchange of facts and theories were to be set up. This has been accomplished in some measure by the organization of the Acoustical Society of America, but so far its membership is not yet representative of the widest interests in this field. The first issue of its quarterly Journal has made a very real contribution, however, and much good will follow. Within the space limits necessarily assigned to this article it is impossible to do anything more than to sketch in the picture of productivity which is going on in this country and abroad. Many of the papers are presented in such generally inaccessible journals that they were unknown even to the reviewer until he set about the task of summarizing the important acoustic events of the last two years since the preceding summary was published (60).

*Theory of Audition.* The tendency now seems to swing somewhat away from a modified Young-Helmholtzian theory of analysis by sympathetic resonance and to emphasize for the moment some form of central function, not that practically all of the facts of analysis are relegated to the cerebrum, but that some form of synthesis can only be ascribed to those centers where such organization is neurologically possible. The increasing significance of *Gestalt* in psychology and the neurological correlate of the engram or equivalent form of configuration seems to be a more suitable explanation of our outstanding ability to detect simple tones in a very complex clang. This form of explanation comes from several different directions. We have, for example, the outstanding work of Trimble (73) in the field of sound localization together with his contributions to auditory theory (72). He has raised the question

as to whether the binaural differences, such as the temporal phase and intensive factors, are separately operative. His researches indicate that any one of these physical factors may furnish a binaural difference-pattern that results in localization. Localization would then depend upon the nature of the cortical effects which correspond to these physical differences at the ears.

Another suggestion comes from some of the work done by Bouman and Kucharski (6) on the threshold of masking. They find that when the masking tone is lower than the tone which is masked the intensity of the masking tone can be diminished in direct proportion to the increase in its duration. If the masking tone is higher than the tone that is masked the intensity of the masking tone may be increased in direct proportion to the decrease in its duration. In other words, the masking effect of pitch as regards duration is opposite at the two ends of the tonal range. The results seem to point, moreover, to the importance of the central processes involved in this connection. On account of the large magnitude of the durations employed it is hard to suppose that the effect of masking is entirely peripheral.

In a previous study (5) they had already investigated the effect of giving tones of very brief duration and covering a wide range of pitch from 150~ to 1200~. When a duration was used that gave a nearly constant number of periods, 7.5~ to 8~, a new property of sound began to appear at a certain duration that was somewhat variable with the intensity of sound but was relatively independent of pitch. The general effect was that the old clang disappeared at such short durations and a new clang quality was introduced. The implication again seems to be that the hearing of a clang is not exclusively or even principally explained in terms of the auditory mechanisms in the cochlea but must be referred to the more complex processes of perception relegated to the higher centers. The reviewer is, however, not at all satisfied in the basic logic of such inferences until more evidence is brought forth from the physical point of view as to exactly what happens when the duration of sounds is abnormally curtailed. The effect of very short wave-lengths on inherent resonating capacities of the outer and middle ear should also be scrupulously taken into account.

Through the work of Crowe (15) with cases in which anatomical changes had occurred in the labyrinth secondary to cerebellopontile and brain-stem tumors we find further substantiation of the Young-Helmholtzian theory. Carcinoma in the internal auditory meatus had

destroyed all the cochlea fibers except at the very apex with the result that only tones of 64~ and 128~ were heard. The left ear was also similarly impaired for high tones but remained approximately normal within the speech range. This would indicate some form of theory which allocated differences of frequency to separate portions of the basilar membrane.

Tullio (77) has written extensively concerning recent auditory theories, especially as regards the functional relationship of the labyrinth. He agrees with the general trend that assigns tones to the cochlea and noises to the utricular structures. Injury to the semicircular canals causes a lowering of the threshold to auditory stimuli in animals. Sound localization, he believes, is referable at least in part to the semicircular canals. Bonain (4) distinguishes auditory orientation from auditory accommodation and proposes a new theory of audition in terms of the dissociation and diffraction of the auditory waves as they cross the lateral network of the canal of Corti together with a further selectivity of wave-lengths in the tympanic canal. Ultimately the tectorial membrane must produce secondary vibrations that reproduce the primary vibrations of the sound waves. This interference of the reflected wave with the direct wave produces the stationary wave needed to explain sympathetic resonance. The theory is novel and ingenious, but must wait on demonstration and proof.

Pattie (53) has done some further work on auditory fatigue. The observer was first stimulated binaurally with two tones which were sufficiently out of phase to make localization appear wholly on the side with the leading phase. The observer thought he was being stimulated uniaurally. The subject was then stimulated uniaurally on the same side in which phase had led and the degree of intensity in fatigue was measured. These two types of stimulation each lasting for one minute were alternated ten times in one sitting. The results showed that no differential fatigue effect was produced, therefore, the fatigue or adaptation was peripheral. As indicated, the experiment ruled out all subjective factors but the author is aware of a possible loop-hole in connection with fatigue since no third unfatigued ear was available for comparison. Kuroda (34) reports from Korea concerning a subjective tonal experience without an external stimulus. Five observers reported hearing a definite tone although there were some individual differences as regards pitch and intensity. The question arises: Is this tone peripherally produced or central in origin and what relation has it to tinnitus? If it

is central in origin we may here have an analogy to cortical gray just as the experience of black runs somewhat parallel to the experience of silence.

Banister has given us a competent summary of the outstanding facts and theories in audition in the two chapters contributed to the *Foundations of Experimental Psychology.* In the second chapter he had the able assistance of Hartridge (1). Particular emphasis is placed on the theories of hearing and replies to criticism. All of us are particularly grateful for the clear presentation of Watt's work on volume.

West and Barlow (81) propose a theory of audition that rests almost entirely on the varying kinaesthetic effects of muscles attached to the bones of the middle ear particularly of the stapes which is accountable for sensations of intensity and pitch. The region of the cochlea stimulated corresponds to pitch and is entirely dependent upon the speed of thrust of the stapes. Their theory does not adequately describe either the great number of auditory phenomena such as clang analysis, beats, and combination-tones nor does it conform to the requirements of the all-or-none theory and the facts of refractory phase. But it is certainly original in the sense that the chief emphasis is on the motor aspect of the mechanism in the middle ear.

The Young-Helmholtzian theory receives renewed support from Troland (76) who attempts to square it with the principles of modern neurology. The fundamental factor of selective or sympathetic resonance is now assigned to separate nerve-fiber groups. The pitch of a tone is correlated with the frequency of the neural impulse and the difficulty presented by the principle of refractory phase is met by the cooperation of several fibers when the frequency is higher than the time of recovery. Loudness of tone is correlated with the total number of neural impulses passing through a given cross-section in a given group of fibers. Localization is accounted for by the discrepancy in the time of arrival of the two sounds from the two ears at the cortical level. Brightness comes in as the sharpness of the wave-front in a group of fibers and volume as the number of fibers stimulated. While there are still difficulties in the way, the reviewer believes that Troland has gone farther to explain a number of phenomena in terms of a single theory than has any other recent theorist. Enough validity also exists in his theory to give the complicated mechanism in the ear some legitimate work to do, and finally the modern drift in the direction of *Gestalt* is also well rep-

reseated as a cortical affair in terms of complex patterns which account for an organization of unconscious factors.

Meyer (48) has made further contributions toward the function of the cochlea in a paper which frankly rejects what he calls "fantastic 'anatomical' data" by taking into account all that the microscope reveals. His fundamental equation depends upon two essential items: (1) the length or lengths of the phragma involved which may then be translated into the number of sensitive cells stimulated; and (2) the periodicity of their movement. These factors are then dealt with in terms of a hydraulic principle which requires that the basilar fibers be not stretched but merely anchored at their ends to the sides of the cochlea. The theory is carried through an elaborate mathematical exegesis. He also deals critically with experiments that have offered explanations differing from his own and gives a description and illustration of a model which demonstrates his theory.

*Sound Localization.* The work of Trimble together with his supporting theoretical papers occupies an exceptional position of importance in this field for the biennium which forms the period for this review. Beginning with a paper (73) which summarizes his doctoral dissertation he laid down the criteria for the lateral localization of sounds which were produced by discrete impulses of a very short and high-pitched character. He finds that when the stimuli are presented simultaneously or with an interval approximating .06 $\sigma$, a single fused sound was generally localized in the median plane. With greater temporal disjunction trained observers generally localize two distinct sounds in opposite quadrants until these dichotic sounds came to the oral axis at approximately 2 $\sigma$. The relationship between these angular displacements and the temporal difference is approximately linear between .06 $\sigma$ and .126 $\sigma$ with much larger differences in temporal arrival usually above 9.48 $\sigma \pm$ .98 which he considers the diotic threshold. Illusory movements of sound with as many as three phantom sounds were perceived.

In some further experiments (74) Trimble continued the use of the discrete impulse technique through spark-gaps using in general the same technique in regard to temporal disjunction in order to obtain further determinations of the fused phantom sound. Introspectively the observers found that it was experienced in terms of visual imagery of a more or less circular figure. This phantom sound comes to the maximal lateral position when the temporal difference is of the order of .144 $\sigma$. It definitely divides into two sounds, one on either side (diotic) when the temporal difference ranges between

1.546 and 2.48 $\sigma$. Investigating these phenomena still further (75) he attacked that problem from five different directions: (1) as a function of intensive differences, (2) as a function of temporal differences, (3) with intensive differences opposed to temporal differences, (4) with temporal differences opposed to intensive differences, (5) with both factors varied in the same direction. Results indicate that intensive differences give more rapid displacement of localization than temporal differences. Temporal differences are not reducible in terms of his data to terms of intensive differences but they are not as effective as are phase differences in the region of low tones. He thinks that considering the entire range of hearing intensity may be the more effective factor in determining directional perception in auditory space. In another paper (72) he gives a very convenient summary of results thus far obtained by workers in the field, outlining the relative effects and limitations of the intensive, phase, and temporal factors. He comes to the conclusion that a compromise in terms of some form of difference-pattern is necessary at this stage of our investigations.

An ingenious device has been described by Bourdon (7) by means of which he demonstrated the relative importance of changes in intensity, phase, and time of arrival of two sounds led separately to the two ears. The apparatus consisted of a revolving disc. The factors were controlled by manipulation of tubes which led to the ears. He believes that intensity and time of arrival are both operative but questions the influence of phase. To the reviewer's mind, the evidence is not conclusive, although he must confess that he is not absolutely clear about all of the conditions of the experiment. Peterson (54) adds a contribution to the field by determining the frequency-range of the phase effect in sound localization. By using an ingenious heterodyning system he was able to produce pitches ranging from 10~ to 16,384~, while at the same time phase and intensity could be separately controlled. He found the effect of phase to be continuous between 10~ and 8,192~ and that it maintained approximately the relationship of $\Phi/\Theta$.

An extremely interesting set of conditions was introduced by Young (86) when he paralleled, to some extent, Stratton's experiment which inverted the retinal images. Young devised an apparatus which quite effectively transposed sounds that would normally strike the right ear to the left ear and *vice versa*. A number of detailed investigations were carried on with nine other observers but principally upon himself both under conditions of blindfolding

and with normal adjustments through the eyes and motor co-ordinations of the body. It turned out that without the conflict of eyes and ears localization was quite definitely reversed but with the eyes open there was a pronounced visual dominance; that is to say, although the sounds were being transposed abnormally to the opposite ear, proper motor adjustments were made to the outside sources of sound when the eyes were open. This leads the author to conclude that while reversal is possible the organism as a whole readjusts itself motorwise to the new situation. Again, therefore, we find that there is ultimate relegation of localized perceptions to the higher centers which are responsible for large neuro-muscular adjustments in terms of cortical sets. The physiological conditions of localization must, therefore, be sought in configurational changes of muscular tonus.

*Auditory Sensations.* The most recent attempt to systematize the auditory sensations in the tonal field has been made by the reviewer (61). The diagram called, for want of a better name, the tonal bell, had already been published in his text (63) and has been described also by Wheeler (84). Account was taken of the double qualitative aspect of tonal sensations variously designated but most often under the name of 'pitch' and 'quality', the latter of which the author has called 'tonality'. These distinctions were found to be supported by theorists and experimenters alike and by special investigations in the field of absolute pitch consciousness and of colored hearing. They were further validated by recent work on consonance. The basic idea is the spiral of Drobisch which allows pitch to rise continuously but in sweeps an octave apart on a line that is colored red in the laboratory model reaching below the threshold to the upper limit of hearing. The octaves are tied together vertically by blue lines indicating 'tonality'. Provision was further made for the attribute of volume in that the tonal bell has a flare at the bottom and somewhat of a dome at the top giving in cross-section an approximation to Titchener's tonal pencil. If further experimental work should throw this attribute into the discard the tonal bell would then be turned into a cylindrical shape but the spiral feature would remain. The author refers to this dimension as 'breadth'. Finally the spiral is given an accelerated or retarded rise in direct proportion to the number of distinct or discriminable pitch changes within each octave.

A critical review of the auditory attributes reveals to Gundlach (27) the present equivocal condition of at least two of the

four commonly ascribed characteristics. Pitch and intensity are fairly well recognized; brightness and volume hang in the balance. He gives specific directions for demonstrating each one as more or less separate variables. In a siren disc a given number of holes may be punched on concentric circles of different diameters so that on the outside there may be as much as ten times the distance between holes that there is on the inside, using the diameter of the hole as a unit. In this instance, tones from the outside are less voluminous and more intense than from the inside. Volume, however, seems to be the reciprocal of brightness and brightness may be explained by the presence of overtones. He was not able to confirm Rich's work on the liminal values for volume. Lau (37) believes that perceived intensity or loudness is not a direct function of physical intensity or the amplitude of the wave but that it is affected by the reflex influence of the visual percept of the field. Again we see that the sensory attributes are intimately tied up with associations of a perceptual nature in which adjacent cortical areas play a part.

Several additional facts in connection with absolute pitch consciousness have been reported. Gebhardt (25) notes the early appearance of this phenomenal capacity in a child of preschool age. At two years of age two different instruments were clearly distinguished and there was recognition as to whether the violin or piano were played alone or whether they were played together. At three a new street-car was recognized in terms of its different clang. Between three and four the notes on the piano were called off with few errors. At four years of age the child began to sing very accurately. Triepel (71) notes the persistence of a definite system in absolute pitch consciousness which was usually correct but always one tone too high. Experience showed that the father had trained the child on a French piano which was low in pitch.

*Consonance, Dissonance, and Musical Intervals.* A number of scientific studies continue the work in this interesting field. Wever (82) has published an investigation in two sections concerning beats and related phenomena resulting from two simultaneously sounding tones. He outlines three stages which partly overlap each other: (1) oscillations of intensity, (2) pulsations of pitch, (3) responses without intermittance. If the two sources are of equal intensity the clearest beats are produced but the regulating factors are the relative and absolute region of pitch, the relative and absolute intensity, and the criterion of judgment. He found a critical interval at which intertones and the two primaries are separately perceptible.

The lower threshold for the beating phenomenon is largely determined by the observer's patience. The author has perceived beats as low as one beat in two minutes. In the second section the beats of mistuned consonances are investigated. The author deals separately with three theories that apply to complex tones (clangs) as follows: (1) overtone theory, (2) transformation theory, and (3) resultant displacement theory. The author rules out the overtone theory as an incomplete explanation. The second theory assumes that a series of partials is produced within the auditory mechanism as the result of a strong stimulation by a pure tone. This the author admits, not only as regards overtones but combination-tones as well, even when these tones are not directly perceived. The resultant displacement theory stipulates that the pulsations which we hear as beats correspond to a wave obtained by adding the amplitudes at all points, the beats themselves being represented by regions of maximal amplitude in the resultant wave. This theory proves to be inadmissible, however, partly because what may be visual analysis when the conventional curves are drawn has still to be proved as auditory analysis in terms of a complexly presented wave. Another reason for dismissing it is the general acceptance of Ohm's law which would make it difficult to account for peripheral analysis in one breath and peripheral interaction in another. The author concludes this study with a statement regarding auditory theory and votes definitely in favor of the Helmholtzian resonance-place type of theory. The reviewer heartily agrees with him on the basis of the outstanding fact that while other theories have explained a few specific phenomena the Helmholtzian theory has accounted for a larger group of related facts. While there is a general drift towards greater participation of the central areas due to the perceptual character of most of our experimental results the operation of the peripheral mechanism is most satisfactorily explained by some form of modified sympathetic resonance in connection with the basilar membrane.

Hauge (30) made a study of beats with respect to the alleged phi-phenomenon found in vision. The problem involved the relations between the beating complex and the intensity of the two generating tones. He investigated the effect on the beating intertone while the intensity of one primary was decreased at the same rate as the intensity of the other was being increased. On the basis of observations by four individuals the writer concludes that through his technique the phi-phenomenon is not applicable to the concept of beats. No perception of auditory movement was reported. Movement

as such when it did occur was merely inferred. An intertone was heard when the respective intensities of the generating tones were unequal, in which case it approximated the pitch of the more intense generating tone. When the intensities of the two generating tones were equal or nearly so, two intertones were heard, each one nearly equal in pitch to that of its respective generating tone.

After distinguishing between *interval quality,* or the phenomenal characteristic of intervals that gains recognition regardless of fixed frequencies but in terms of a fixed ratio of frequencies involved, and *distance,* which indicates the absolute tonal separation, Pratt (55) continued his former studies, reviewed in a previous summary (62) by bisecting intervals larger than an octave. Below the octave bisection follows the geometrical mean or an equal division of the ratios of frequency fairly uniformly; above the octave, however, this is not the case. Four intervals were used, one slightly larger than the major ninth, one about half way between the eleventh and the diminished twelfth, one the just twelfth, and one slightly smaller than the minor fourteenth. Pratt believes that the difference between these and his former results lies in the difference of the observer's attitude. If he judges in terms of a *musical interval,* the midpoint still coincides approximately with the geometrical mean but if *distance* is the criterion this point will move along toward the arithmetical mean. Concentrating then on *distance* in another study (57) he asked his observers to compare a variable interval succeeding a constant interval in terms of *distance.* During one-half of the series the temporal order of the tones forming the respective intervals was reversed. This study verifies his former conclusion in connection with the usual change in attitude when the interval exceeds an octave. In the region of an octave and a half the apparent size of the interval is increased by about as much as a minor second. The reviewer wonders whether the conditions of both experiments did not tend to move the observers away from the natural musical setting surrounding interval relationships when he admits that they judged fifths differently in different regions of the tonal register. In the former experiment the traditional *Aufgabe* persisted within the region of its most frequent operation; in the latter the requirements of the experimental series were more rigorously lived up to. The author is quite right, however, in making the distinction which in the reviewer's opinion is an analog to the situation which makes *c* and *c'* more alike than *c* and *d.*

In a third study (56) Pratt makes a very useful diagnosis of

quarter-tone music. He thinks that size of intervals has little to do with pitch discrimination since a change in size can not be detected if one of the tones is slightly raised in pitch but well above the normal threshold for pitch discrimination for that region. In the middle register a change of 20 cents is noticeable but gives only 50 per cent right judgments. An unqualified 100 per cent correct answers can be obtained only when the change is 50 cents. The reviewer is reminded of that fact that in violin playing and probably in singing the minor third is flatted and the leading tone sharped not to play "in pure intonation" as is frequently erroneously stated, but to emphasize the given effect without losing sight of the range within which the interval would still be recognized for what it is. The author sums up his analysis by quite correctly insisting that the musical significance of an interval is influenced by other factors than perceptibility. The imaginal features of the percept have at least equal rights with the sensory constituents.

Densmore (16) revives the question as to the reason for the deviations from the semitone scale found in Indian music. While the Indians are more susceptible to the significance of sound of many types that are imperceptible to us, certainly their pitch discrimination and probably their auditory acuity is not greater than ours. After analyzing some 1,700 phonographic records of their music she concludes that the reason lies in the lack of a conventionalized system of music and an emphasis, on the other hand, on individual expression.

Metfessel's monograph (41) on negro music makes claims in the direction of a new and vigorous attack on certain psychophysical relationships in primitive vocal and facial expression. By combining ingenious devices and by using a new musical notation, he was able to record both the facial expressions and the intonations of the singer and later to analyze the effects recorded. The monograph is replete with detailed accounts of a variety of songs as sung by many different singers under varied conditions. It treats of the emotional expression, the use of the vibrato, the specific analysis of many songs in terms of an elementary, objective, and unbiased attack on a type of music which is so unlike our own that any subjective appraisal and analysis allows the vitiating factor of our perverted perception to enter and thus to color the conclusions drawn. The study deserves a separate and longer review.

There continues to be an active interest in the more fundamental questions surrounding consonance. Metfessel, as we noted in a previous review (60), re-emphasized the close analogy between har-

mony and melody that Bingham and Stumpf, among others, had discussed in the historical literature. Now Kollarits (33) from another angle suggests that fusion and assimilation can not be sharply separated. The running course of a melody approaches the harmony of a struck chord, especially if it is struck *arpeggio*. There is simply a fusion of a whole series of images in a pattern in the melody, whereas in the chord there is a fusion of two or more whole images. This theory, as was Bingham's years ago, is motor in type. One of the most thoroughgoing and scholarly studies recently made is contributed by Guernsey (26) who took as his problem an attack on and an evaluation of various criteria which have recently been discussed in connection with consonance: fusion, smoothness and affective response. Both musical and unmusical observers were used and control apparatus was devised to give both pure tonal and complex tonal stimuli. He concludes that consonance, within the strict interpretation of its musical meaning, can not be judged adequately in terms either of fusion or smoothness. Tonal fusion becomes then not a perceptual but a sensorial phenomenon absolutely different from its æsthetic or affective experience. Smoothness is likewise inadequate as a single criterion because of the divergence in connotation in the mind of the listener. The author believes that pleasantness and unpleasantness in the last analysis are the most legitimate criteria to use in the musical setting in which consonances and dissonances find themselves. The criteria which have been traditionally used in experimentation are influenced by too many factors, like intensity, clang, and temporal sequence, to be scientifically accurate. He closes his paper with interesting applications to some actual musical compositions and theoretical situations. Incidentally the minor second stood out as occupying the lowest position of consonance in all series.

Guthrie and Morrill (28) confirmed Brues' experiment on the fusion of nonmusical instruments by the use of a technique different from that reviewed in our previous summary (60). Using Stern variators 44 intervals were produced ranging from perfect unison to an interval beyond the fifth. The observers ranked each pair as pleasant or unpleasant and again in terms of consonance and dissonance. All 372 observers were taken from an elementary class in psychology and knew the terms presumably only in a general way. The curves for pleasantness and consonance show a high agreement. All of these studies would raise the question whether the affective response should be left out of account in the test of consonance as applied to musical ability.

An unprejudiced investigation was conducted by D. L. Larson (35) in connection with the Seashore consonance test answering at the same time several objections made by Heinlein. The main problem involved a strict adherence to the instructions which accompany the test requiring the observer to judge cognitively instead of affectively but admitting at the same time that the instruction as presented in the manual accompanying the test is probably not as emphatic in its direction as it might well be. The results were statistically treated in terms of correlations and the outcome showed that the procedure of comparisons of paired intervals which was criticised by Heinlein was adequate for testing consonance and did not lead to harmonic progressions which perceptibly disturbed the scores. If the instructions are literally followed the consonance test proved reliable either as a group or as an individual test in terms of retesting. With affective judgments eliminated under the controlled conditions of the experiment, observers with pronounced musical ability scored relatively higher than those without such musical capacity. Some of the criticisms are admitted in the discussion that follows.

*Pitch Discriminations and Auditory Acuity.* It is now fairly well established that work on pitch discrimination must go hand in hand with the investigation of auditory acuity. In view of an increasing number of investigations it were folly to test only one or the other of these attributes without either keeping one of them constant or else, as is more frequently done, investigating the one factor in terms of a wide range of the other. The common practice seems to be to treat one functionally in terms of the other and to plot both graphically in terms of ordinates and abscissæ. Bunch is continuing his work in audiometry with abnormal cases using groups of normal subjects as a check. In one of his studies (10) he points out that the traditional explanation for the loss of acuity for tones near the upper limit has been interpreted as a lesion of the auditory nerve. By means of ordinary standardized techniques such as are used with the Western Electric 1A audiometer the upper limit for hearing high tones at the intensities available in the apparatus is considerably below limits established by more intensively given tones. One case yielded audibility at 5,760 ~ on the Western Electric 1A audiometer and 11,000 ~ by means of the monochord (Struycken modification). Through bone conduction this was raised to 23,000 ~ in the left ear. Many cases of so-called deafness, therefore, turned out to be a loss in sensitivity. Bunch (9) also investigated 353 cases at various age limits from twenty to sixty years where at any stage there was no

subjective indication of deafness. A wide range of tones was also used (32 ~ to 16,384 ~). At 1,024 ~ and below he found that the scattering of results was quite uniform with considerable broadening for higher tones and a most marked effect at 8,192 ~. With reference to your various ages at the decades studied he found little difference with age under 512 ~ but a decreasing sensitivity in the higher octaves. One curious result which is hard to explain was a very definite determination that for the sixty-year-old group the average threshold for 512 ~ was lower than in all other age groups. Why people of this age should hear better in this middle register than younger individuals requires further investigation and explanation. He has also worked with a case where the entire right cerebral hemisphere was removed (**8**). When the patient had completely recovered from this excision no disturbance occurred in the perception of pure tones or spoken words. This is another instance following the work of Franz, Lashley and Cameron which points to the tremendous amount of reserve function that is available in case of an emergency and the necessity for emphasizing the complete integration of function rather than specific localization.

Corbeille and Baldes have made two studies (**13**, **14**) on responses to acoustic stimuli in intact and decerebrate animals. In one case with cats, dogs, frogs and rabbits respiratory changes were noted and in the other cardiac responses in rabbits. In the latter case the Einthoven galvanometer was used. An electric oscillator and loud speaker produced the sound and records were taken only after the animals were emotionally adjusted to it. These studies add material to an already long list of researches gathered by Diserens (**18**) in a book which has been separately reviewed in the PSYCHOLOGICAL BULLETIN. In the case of frogs prolonged tones decreased the respiratory rate whereas short rapid tones increased the rate. While analysis was made of the effects at the onset of the stimulus, during the application of the stimulus, and during the after-effect of the stimulus, only the second and last of these situations yielded consistent results. During stimulation the rate of breathing was decreased for both types of stimuli whereas in the after-period the rate was increased often considerably above the normal. The decerebrate frogs and rabbits responded in the same way as those which were kept intact as far as breathing was concerned but the intact rabbits showed decreased heart-rate while the decerebrate rabbits showed no effect. In a few cases the heart-rate was increased in the decerebrate animals.

Several papers have attempted to evaluate tests of auditory acuity in terms of the larger hygienic program involved. Barwell (2) seems to think that the various tests have a place in the field of nerve-deafness, middle ear deafness and otosclerosis. Various precautions for their use in these connections are stated. Beivie (3) enlarges this program for the prevention and control of defective hearing. Four types of activity in this field are outlined: (1) the study of the hereditary basis of some of the types, (2) the training of obstetricians on the detrimental effect of prolonged labor on the part of the mother and the necessity for immediate cleansing of passages together with the elevation of the head of the new-born, (3) the education of workers and employers in matters of industrial hygiene, and (4) the protection from the effects of detonation in the army and navy. Some studies have also indicated the serious practical problem of deafness in our population. Morton (50) estimates that there are three million public school children in this country who are afflicted with incipient deafness. About four-fifths of these can be kept from becoming deafened adults by giving them proper vocational guidance. Lemcke (38) shows that deafness is more serious than restriction of visual acuity or other visual defects since it often involves a moral deterioration. By separately housing children afflicted with this malady disturbing inferiority complexes may be avoided.

Carrying on similar experiments on frogs Corbeille (11) found again that sounds from 100~ to 8,000~ caused respiratory retardation for the duration of the stimulus but short repeated sounds caused acceleration. The same results followed decerebration above the optic lobe in another set of frogs, hence the conclusion that in this group of animals the cortex is not directly involved in this response. Further experiments by the same author (12) on the cardiac responses of rabbits to sound showed an invariable effect in the direction of retardation of the heart-beat. If stimulation lasted from 15 seconds to 1 minute 5 seconds, the rate returned to normal. In 60 per cent of the cases decerebration destroyed the effect, indicating perhaps a bulbar reflex pathway.

Upton (78) furnishes us with a useful summary of the recent investigations on auditory sensitivity among the higher vertebrates. The general impression obtains that many of the mammals hear noises but not tones as such. The author criticizes the results, however, in terms of the procedures employed since the tones involved played so small a part in the total situation to which the animal responded. He therefore discards the procedure in favor of a con-

ditioned breathing response used with four guinea pigs. Tones of 600 ~ did not at first modify the breathing rate, but when later conditioned with an electric shock there was a definite breathing response during stimulation and a return to normal after the cessation of the stimulus. That this response was to a specific tone was proved by testing with one of 1,000 ~, when no response was elicited.

There has been unusual activity again in the field of auditory sensitivity occasioned, as was before noted, by rapid advances in electrical apparatus largely of the oscillating tube type. Kellogg (32) using an oscillator devised by Halverson and noted in our last review (60) started out to establish the auditory intensive threshold in terms of electrical units. Through suitable equations the scale readings in centimeters were converted into millivolts. The premises underlying this conversion were examined and found to be approximately true. The intensity of tone appears to be linearly related to the amperage required to produce it. Threshold values are obtained both in millivolts and in per cent values of standard stimulus. Riesz (58) employed currents from two oscillating circuits which were alternately and automatically switched to the observer's telephones about three times a second. When fluctuations in loudness were reported the result was noted. Weber's law held provided the intensity was not less than $10^6$ times the minimal audible intensity but varied slightly from tone to tone (35 ~ to 10,000 ~). The variations lie between .05 and .15. Wever and Truman (83) tested out the course of the auditory threshold in the presence of a tonal background, in order to parallel the situation which usually obtains in everyday life where sounds have to be distinguished not in absolute silence but in the presence of other sounds. In general, they found that the threshold is at first very high in the presence of the ground-tone as compared with conditions of quiet but with repetition its value is reduced until it approaches normal hearing. This level of sensitivity proceeds at an ever decreasing rate until after about two minutes it has practically ceased even up to nine minutes of stimulation, but it is never quite as low as when the background is entirely quiet. Some attempt is made to invoke the *Gestalt* theory in terms of figure and ground suggesting a change in the observer's total experience making it appear somewhat analogous to visual phenomena.

Onoshima (52) contributes an interesting study which parallels in man some of the work that has been done with the lower animals. According to the *Gestalt* theory, he proves that the judgment of an

equal pair of comparison tones on the criterion of intensity depends upon the rhythmical *Gestalt* of the whole series. A shift in the rhythmical pattern will very much disturb the judgment of groups of tones. Although it is not directly stated, some configuration of the same sort must be involved in the study of Kreidl and Gatscher (33a) who dispute Stumpf's statement that a tone sounds higher in pitch to the right than to the left ear. In their work an individual difference appeared which could perhaps be explained by a difference in cortical set or *Aufgabe,* in that in some individuals the second excitation was generally heard higher in the right ear, while in others it was heard higher in the left ear.

*Apparatus.* Hartmann and Trolle (29) have developed an air jet whose velocity is higher than that of the sound which serves as the fundamental. They propose it as a new acoustic generator and offer an historical and theoretical discussion together with charts, drawings and photographs. Dimmick (17) also suggests some new auditory apparatus which is built on the principle of the oscillating circuit and produces relatively pure tones over a wider range than the full set of Stern variators by the method of beat-frequency. He was able to obtain tones from the lowest audible tone to one near the upper limit (20~ to 9,000~) but tones even lower (4~ to 5~) were heard by means of a telephone. The tone is proved to be sinusoidal. Above 5,000~, however, harmonics appear.

Miles (49) claims that if weights are set at unequal distances on the respective prongs of tuning forks, the prongs are likely to vibrate at the same frequency but with different amplitudes, thus influencing the total duration of the tone produced. Photographs and a bibliography are included. Metfessel and Tiffin (46) give a brief description of their new Phono-Projectoscope. This very useful and much needed improvement over the Koenig rotating mirror, consists essentially of an horizontally rotating drum with six projecting and reflecting plates. By this means the optical lever is spread out in the usual fashion over a much broader field and a clear demonstration is afforded of the analysis of the form of sound waves. A photographic method of measuring pitch is described in some detail by Metfessel (42, 43) who utilizes the stroboscopic principle to do away with the tedious and expensive method of measuring wave-lengths after they have been recorded. The photographic film serves as the graphic paper and the mode of recording thus shows the deviation in wave-length or frequency. An example is given illustrating a graph of Galli-Curci's voice on two short notes. Fritz (23)

suggests an apparatus for measuring the reaction time of white rats to noise. The experimental animal is placed in a basket which is conical in shape and has an aluminum disc as its base. This is suspended in such a way by a rubber band that movements will be registered by means of electric contacts which alternately make and break the signal current.

The bound volumes of the *International Critical Tables* furnish an exceptional reference library for authenic information in acoustics. The following instances give an adequate sampling of what each volume contains. Watson (80), for example, tabulates the critical values in connection with sound generators. He gives the data concerning the relation of the frequency of tuning forks to temperature and to amplitude of vibration. In the same way he discusses the acoustic amplitude and efficiency of telephone receivers in relation to the frequency of the current. Devices are also suggested for stabilizing the frequency of oscillating currents. Sabine (64) discusses the transmission, reflection, reverberation, and absorption of sound. The values are given for transmission through tubes, horns, and wave-filters. Similarly tables show the effect of various types of septa bounded by air, such values being given for quilts, wood, glass, and steel. Acoustic absorption is likewise dealt with. Fletcher (20) gives detailed figures on the masking effect of sound and on the sensitivity of the human ear. Foley (21) notes the velocity of sound for different media. In free air and in illuminating gas this velocity is apparently independent of pitch but not independent of intensity especially at high values of intensity.

*Psychology of Music.* Interest still centers in many branches of the psychology of music. There is much discussion of the adequacy of musical tests as an index to musical talent. Heinlein (31) wonders whether the degree of difficulty in the test for tonal memory can be measured by the length of the span of tones to be remembered. Talented individuals think in terms of melodic patterns and the tendency is pronounced in these individuals to avoid the instructions which require counting. Melody involves a motion of pitch that may be either acute-oblique, horizontal or grave-oblique. Cutting across these motions are the factors of the rhythmic pattern and the place of pitch in the tonal register. He does not think that the tonal contour given in the test can be avoided. In a similar vein Lowery (39) notes that listening to music is like reading. The tones become the letters of the word or the words of a phrase and need not, therefore, be individually recognized. One may be able to hum

the melody correctly without specific attention to the notes by following the meaning of the passage or pattern. He does not believe that the Seashore test stresses sufficiently the musical form as a whole. And so he selected distinctly musical phrases in his investigation with 130 children, twelve to fourteen years old. The initial phrase was given three times and was followed by examples somewhat modified by transposition, embellishment, diminution and augmentation. He found that scores on this test were significant and that general intelligence played a distinct part in the recognition of memory and cadence but showed a zero correlation with the scores for the test on phrasing.

Fracker and Howard (22) have investigated the correlation between intelligence and musical talent among university students, 230 of whom were tested at the University of Arkansas. Intelligence scores were derived from the Otis Self-Administering tests and the Army Alpha test. The highest correlation ($.32 \pm .039$) was between pitch and I.Q. Some of the previous scores had been considerably higher but the authors agree that general intelligence favors the securing of a good record especially in the first test and that of necessity no high correlation between musical ability and intelligence need be expected. Conversely, however, outstanding musicians are usually persons of great intellectual achievement.

Stanton (69) has published in monograph form an extended evaluation of the Seashore tests in connection with their practical application over a term of years at the Eastman School of Music. This monograph deserves more extended review. She has been able to justify the giving of these tests for the purpose of prognosis and of classification within various divisions of the school. That these classifications were satisfactory was borne out by the mortality of the low group on the one hand and the predicted achievement of the high scorers on the other. The forms used for rating and case-records together with other criteria are added. She also (68) makes a report in the Seashore Commemorative Volume in which she shows that in various studies the teachers' talent ratings were fairly well matched by the test scores before this procedure was used for admission to the Eastman School of Music. Both of these studies constitute, so far, the outstanding trial in practical school work which these tests have received.

Three of the Seashore tests have been tried out with preschool children by McGinnis (40): intensity, pitch, and consonance. There are naturally several difficulties to be faced: the length of the task,

the comprehension of the terms used in judging, and the uninteresting nature of the material; but the writer believes that they are adaptable with some slight modifications in the direction of shortening the series and increasing the interval between judgments. The correlations are found to be comparable to those obtained in other investigations, but, of course, there are more omitted responses. Curiously enough in view of other trials, the consonance test was found to be fairly reliable. W. S. Larson (**36**) used the tests for purposes of prediction of success in public school instrumental classes, especially with orchestras. Detailed analyses of scores made in the several tests are given with the general result that tests for pitch, rhythm, and possibly intensity, give slight indication of probable success in beginning classes. Tests for time, consonance and tonal memory are apparently of little value here. Tests for pitch, intensity, consonance and rhythm are significant for those who continued into the junior high school orchestra; all except those for intensity are significant for those who qualified for the junior high school advanced and preparatory orchestras; and all six tests without reservation were of still greater significance in selecting the membership of the high school advanced orchestra. Nielsen(**51**) concentrated on the problem of training and the predictive value of the rhythm test. Ten poor and ten good students from the School of Music at the University of Iowa who were used as observers showed that the test correlates significantly with musical ability and performance, and that motor rhythm can be slightly improved in the early period of training. These statements, however, do not hold, he finds, in connection with the ability to tap out a rhythm.

Gaw (**24**) offers five contributions to the Seashore Commemorative Volume: a sight singing test, a modified time discrimination test, a modified form of tonal memory test, some fifth grade norms obtained by means of the Seashore test, and some preliminary studies on pitch discrimination at Mills College. While these tests, for the most part, were not done in sufficient number or under rigorously controlled conditions they do offer suggestions by way of adapting tests to situations involving musical ability.

A number of studies have dealt with the question of the vocal vibrato. Metfessel (**45**), who is an outstanding authority in this field, has analyzed some new examples of vibrato in accordance with wave-frequency, amplitude, form, and periodicity. After studying some 615 different cycles he finds that the extent of the vibrato in frequency is about one-half step ranging from one-fifth to a whole

tone and that the periodicity is 7 cycles per second with greater uniformity in rate than in extent. Four types are distinguished with respect to relative length of crest and trough. A general account of the vibrato as found in connection with such celebrated voices as Caruso, Galli-Curci, Chaliapin, McCormack and Homer is described by him (44) in an article which describes the part of the vibrato in producing the æsthetic effect in music. He contrasts the analytical attitude of the laboratory and the effect of fusion produced by the vibrato at a concert. The former makes science; the latter makes for enjoyment. In a brief note William (85) summarizes previous investigations on the extent of the vibrato as carried on in the University of Iowa laboratory. He differs with Metfessel in the interpretation of the discrepancy between the results obtained by Schoen and other investigators in regard to the pitch-range of the vibrato. He does not believe that the discrepancy is due to the presence of overtones but to the rate at which the phonograph record was run and the tendency of the tonoscope to respond to multiples of the original rate. Wagner (79) has published a thesis that shows how well the vocal vibrato may be controlled and developed through ingenious breathing devices used with a wide range of observers. Through the use of models from artists' tones he was able to cultivate the vibrato where none before existed and to refine the control of the rate of vibrato through the influence of rhythm, and the extent of vibrato through rhythm and controlled respiration. Numerous graphs showing the final accomplishment of his observers, among whom were both children and adults, are presented.

Stevens and Miles (70) have worked out the question of attacking the tone during singing. Ten men furnishing 360 records proved that the human voice raises its pitch from 1 per cent to 3 per cent within the first one-fifth of a second of singing. Later the rise is more gradual and by the end of one-half second there may be even a slight tendency to lower the pitch. Humming is less certain as a mode of attack than is open singing and singing on a full breath seems also to improve the attack. Previous singing at about the same level of pitch is the best guarantee of a successful attack. The study is unique in that the Dodge microscopic recorder was used. Root (59) has made an extensive analysis of pitch-patterns and tonal movements in the speaking voice. He finds that there is much similarity between the melodic recording of song and the cadence of speech. A number of standard addresses were analyzed by fourteen trained observers who were ignorant, however, of the purpose of the study. The results

showed a high degree of consistency among the reports. The method of phonophotography was also resorted to in another section of the investigation. In both sets of records individual differences in the evenness of pitch appeared, but, on the whole, there were manifest tendencies toward definite pitches and characteristic pitch-patterns which were analyzed in detail. Musical intervals in both sets of records were also approximated. Similarly the syllabic pitch-patterns and transitions from syllable to syllable were scrutinized in terms of seven criteria which are given. Metzger (47) has entered the controversy concerning the mode of vibration of the vocal cords in a thorough-going study and with very careful technique. A part of the technique involved swallowing small X-ray plates so that a photograph might be obtained from the front of the throat through the vocal cords which as a result of his study he prefers to call voice-lips. He finds no alternate action of these voice-lips but what he calls a 'cushioned action.' The pharynx does not change to the next octave above or below but the change of voice both from one register to another and during adolescence in boys is due to an interaction between the voice-lips and the bronchial resonance. A comprehensive survey of both speech and hearing is now available through Fletcher's (19) new book which is worthy of an extended review in the PSYCHOLOGICAL BULLETIN. He summarizes in a completely competent way the outstanding facts with regard to the recognition of sound and the basic principles underlying hearing. His numerous and notable contributions to this field ought to guarantee him an attentive audience.

In a short study Sherman (67) reports the effect of the emotions of surprise, fear-pain, sorrow, and anger-hate as expressed in terms of a single vowel repeated five times. The observers were to tell what emotions the singer intended to convey. Intensity, duration, and pitch were kept constant and visual cues were eliminated. While the investigation was sketchy in character, sorrow and anger-hate were rather well detected. Fear-pain was always conveyed and surprise showed little effect. The study is more indicative than authoritative. Sapir (65) gives us a very suggestive study in phonetic symbolism. He distinguishes two forms of meaning found in words, the dissociated or referential type found in the transition from 'boy' to 'man' and the expressive type conveyed by a change in intonation or of vowel quality. Examples of the second are the change from the interrogative to a rhetorical question or the change from 'tiny' to 'teeny.' He demonstrates that there is a wide

individual difference in responsiveness to such sound contrasts and outlines a number of various significant results obtained with the use of disyllabic nonsense words. Observations show that auditory and kinæsthetic factors are involved in the meaning. Schoen (66) summarizes the æsthetic attitude in music and the literature that has accumulated. He analyzes the question of the beautiful and the associations which come to the well-informed listener. It is epitomized by the statement, "the beautiful in music lies in 'listening to music,' and not in 'hearing music'." The essential fact is that to get the most adequate enjoyment out of music one must try to understand the basic musical form in terms of the meaning which it expresses. Music, he says, furnishes "the ideal conditions for beauty as a self-sufficient, complete in itself, intrinsic experience."

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# TOUCH AND KINESTHESIS

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A large number of studies have appeared in the field of touch since the publication of the last summary of the literature on this topic.[1] The number of studies allotted to the temperature sense or to the problem of establishing the specific end-organs of temperature is perhaps greater than that falling to any other aspect of touch. The relatively unexplored field of the sense of vibration claims the attention of a noteworthy group of investigators. Attention is called to several important investigations which indicate specific facts in regard to the nature of the sensory discharge of impulses in cutaneous end-organs. While the experimental results of these recent studies in many instances support the existing theories, in others they flatly contradict certain of the theories of touch. Owing to lack of agreement between experimental fact and theory, suggestions in the way of new theories are submitted.

In contrast with the large number of studies on touch, there are relatively few contributions to our knowledge of the kinesthetic sense. With few exceptions, these studies have only an indirect bearing upon kinesthesis, such as its rôle in a learning situation or in the perception of space. There are several articles which are concerned with clinical problems, but with few exceptions, both as regards the cutaneous and kinesthetic articles, the conclusions and generalizations advanced are supported by carefully prosecuted experimental work.

*Receptors.* A number of articles deal with the problem of cutaneous receptors, and several present results as to their depth in the skin. The majority of these investigations are limited specifically to the attempt to locate, if possible, the receptors of the temperature sense. The most significant net result is the failure of these investigators to reach any noteworthy agreement in regard to the specific end-organ for either of the temperature qualities.

Dallenbach (17) indicates the two methods, direct and indirect,

[1] JOHN T. METCALF, Cutaneous and Kinesthetic Senses. *Psychol. Bull.*, 1928, 25, 569–581.

which have been used to locate the end-organs of temperature. The direct method, by which tissue is extirpated and examined, has given negative results. The indirect method, used first by Donaldson and by Goldscheider, has led to "positive correlations which, though tentatively advanced, have been dogmatically accepted." The same author (16) finds that the punctiform method of localization of temperature spots yields a significantly higher degree of correspondence in repeated surveys of the same area than the traditionally used moving method. Twelve sources of error in the latter method are designated. He finds that, by the use of the punctiform method, the warm spots are as numerous as the cold spots. Histological examination fails to reveal end-bulbs of Krause and Ruffini cylinders in the skin beneath these spots.

Pendleton (75) uses the "best histological technique available" and fails to find Golgi-Mazzoni end-bulbs in the hairy parts of the skin at which cold spots had been localized. These terminals are found, however, in the palm of the hand. By measuring the limen of the same cold spot before and after removal of a layer of skin of known thickness, a method is contrived by which it is estimated that the cold receptor is located in the stratum of Malphigi. Free nerve endings and the hederiform nerve endings of Ranvier, the latter of which are found in warm blooded animals only, are found in this layer. The latter are designated as possible receptors of cold.

Strughold (92) explores the sclera and cornea for sensitivity to cold, and presents evidence in support of the view that the end-bulb of Krause functions as the cold receptor. He finds the threshold of cold to be lower at points beneath which the end-bulbs of Krause are more superficially situated, and the density of cold spots to be greater in parts under which the organs of Krause are more closely collocated. Gilbert (41) reaches a different conclusion as a result of microscopic examination of portions of skin, taken from seven different parts of the body. Pacini corpuscles are found, especially in the skin from the sole of the foot, but end-bulbs of Krause and Ruffini cylinders are not found anywhere. It is assumed that the technique which reveals the Vater-Pacini organ should also expose any other encapsulated end-organ.

Adrian and Umrath (4) secure records of the discharge of impulses which follow the excitation of the Vater-Pacini corpuscle under the flexor tendon of the cat's toe. They find that these organs respond to mechanical, but not to thermal stimulation. The records of the discharge of impulses resemble those obtained in the living

animal when pressure is applied to the toe-pad. The Vater-Pacini corpuscles are accepted as the receptors of pressure applied to the skin and of changes in position at the joints.

Having determined the latent time of the sensation of warmth, Hahn, Boshamer and Goldscheider (50) estimate that the warm receptors are not more than .1 mm., and most probably only .07 mm., below the skin surface. The intraepithelial nerve endings are indicated as the probable receptor of temperature. Pütter (80) also attempts to determine the depth of the end-organ of temperature. He finds that the size of the difference limen of warm varies inversely with the duration of the stimulus up to .8 to 1 sec., beyond which there is no change as a function of time. In dividing the amount of temperature change by the duration of the stimulus, a constant is found, from which it is calculated that the warm end-organ is in the stratum corneum at a depth between the limits of .012 and .032 mm.

*Temperature sense.* The contributions to the temperature sense throw light upon various conditions of thermal stimulation. A number of studies deal with certain phases of the problem of thermal adaptation. Hahn (47) analyzes adaptation (Umstimmung) into two phases: *adaptation to stimulation* (Abstimmung), during which sensitivity is reduced, and *recovery from adaptation* (Anstimmung), during which sensitivity returns to the normal status. At low intensities, adaptation to stimulation reaches complete insensitivity, but at higher intensities there is reduction only to a constant level of sensation. The more intense the thermal stimulus, the more rapidly the phase of recovery from adaptation takes place. Using both external and internal (diathermy) stimuli, François and Piéron (25) demonstrate that thermal adaptation consists of a state of equilibrium in a zone within which thermal sensitivity disappears.

Von Frey (27) says Weber's theory of temperature is apparently contradicted by the fact that warm is not experienced immediately upon removal of a cold stimulus. He points out that this will occur, however, if precautions are taken to make sure that warm organs exist in the region of stimulation and if a Holm guard is used to insure the reduction of temperature does not extend beyond the area covered by the cold stimulus. Hahn (45, 46) finds that the two hands experience no difference in temperature sensation when placed in a common bath immediately after each has been separately adapted to very different temperatures. He shows that the temperature sensation is entirely independent of the rate and degree of temperature

change. He concludes that the adequate stimulus for the temperature sense consists, not in the matter of change in temperature as Weber believed, but in the absolute temperature of the sense organ itself. Experiments in which they find that adaptation to any temperature above or below physiological zero alters sensitivity uniformly throughout the thermal range between physiological zero and the temperature of adaptation prompt Hahn, Goldscheider and Bruch (49) to formulate the concept, *zone of adaptation* (Adaptationsbreite). They derive another concept, the *law of constant sum,* from their discovery that the sum of any temperature of adaptation and the subsequently determined just noticeable difference in temperature represents a constant at all points in the range of temperatures. Thus, after adaptation to 33 degrees, the difference limen is .9; to 30 degrees, about 4; and to 10 degrees, about 24 degrees C. Piéron(77) shows that, after a period of adaptation, the threshold of temperature is altered, while that of the burning experience which is associated with thermal stimulation is unchanged.

Hahn and Lueg(51) and Hahn, Boshamer and Goldscheider(50) claim to have demonstrated that cold and warm sensations may be elicited simultaneously in the same region without fusing into heat. The former study casts doubt upon the existence of simultaneous contrast in temperature experiences.

Bishop (9) has designed an improved heat grill which allows simultaneous application of warm and cold, or rapid alternation from one temperature to the other. Messerle (71) describes a temperature apparatus which keeps the water contained in it at constant temperaure for periods of time sufficiently long to make clinical examination of the temperature sensitivity of patients.

Burnet and Dallenbach (11) and Gritman and Dallenbach (44) present different combinations of warm and cold water through a pair of heat grills, upon each of which the subject places a forearm. The subject is required to make a comparative judgment as to which is hotter. It is found that the number of hotter judgments varies with the size of the interval between warm and cold stimuli when both intervals in any pair are referred to the same standard, but not when referred to different standards. The stimulus value of the different temperatures is found to vary with the distance from physiological zero. An equation for heat intensity is derived in which the warm component is weighted by the constant three.

Straus and von Versen (91) show that recovery of thermal sensitivity after the skin has been anesthetized by the application of

cocaine varies with intensity of stimulation. The results for warm are more conclusive than those for cold.

*Pressure.* Hulin (53) describes an electromagnetic esthesiometer which eliminates certain errors of other electrically operated instruments of the kind. Gatti and Dodge (34) devise a new pressure gauge, which controls precisely the rate and period of application of a stimulus. By stimulating a single pressure spot, they find that the just noticeable difference does not vary with the intensity of the stimulus but is an absolute constant. In another study, Gatti and Dodge (35) use a refined technique by which changes in the deformation of the skin under varying degrees of intensive stimulation may be observed. They reach the conclusion that physical pressure (gr./mm.) is a less satisfactory measure of the adequate pressure stimulus than their new formula which expresses the adequate stimulus in terms of the depth of deformation divided by the cube root of the total weight squared.

Fischer and Grundig (24) determine that the skin is normally more sensitive to tangential than to direct or vertical pressure. They glue thin metal discs on the skin and apply pressure vertically or tangentially by means of hooks which are fastened in the center or edge of the disc. The threshold for tangential pressure is smaller for all dimensions of disc used than that for direct pressure. Believing that movement of the skin is responsible for this difference, they determine the tangential and direct pressure thresholds on the knee-cap, where the skin may be moved readily, with the leg in the extended and in the bent or flexed position. The threshold of tangential pressure is found to be much lower in the extended position, but in the flexed position, where lateral displacement of the skin is greatly reduced if not entirely eliminated, the two thresholds are practically the same. The threshold of the skin when under tension is found to be doubled for the direct, and tripled for the tangential mode of application. Von Frey and Strughold (28) find that the threshold of pressure after anesthetizing the skin is greatly increased. The thresholds of pull and pressure after anesthetizing the skin are the same. Owing to the fact that pull is not believed to stimulate the deep tissues, the authors believe they have confirmed Weber's view that the skin is unitary in its function. Previously Lombard (66) asserted that tickle and touch are excited at different points on the skin, but he now concedes that at least certain spots on the skin give rise both to tickle and to touch. Eidelberg (22) reports that sensitivity to wetness and dryness differs in various parts of the skin,

being most acute on the tongue, then on the face, hands and body, in the order named.

Angyal (6) shows that Katz' *surface touch* (Oberflächentastung) is bidimensional, while his *volumic touch quality* (raumfüllendes Tastquale) and *projected touch phenomenon* (raumhafte Tastphänomene) are tridimensional. In volumic touch quality, there is added to the surface touch phenomenon a sensory component of loose, incompact or spongy character. The projected touch phenomenon is described as having two surfaces, one of which rests on the skin and the other parallel to it but separated from it by an intervening loose, spongy mass. A dynamic component is added in cases of vibration or movement. A shift in the attitude of the subject may convert a volumic touch quality into a projected touch phenomenon, or vice versa. The attention is directed to the surface which is not in contact with the skin in the projected touch phenomenon.

An apparatus by means of which a bead fastened on the end of a small rod is moved over the skin at varying rates and intensities is described by von Frey, Fischer and Grundig (30). Movement is found to be more readily perceived at the higher velocities and intensities of the apparatus. At reduced rates combined with low intensity, the moving stimulus is ineffective or gives rise to illusions. The threshold of movement is not essentially lower than that determined by separate up and down movements of the stimulus. Allen and Macdonald (5) attempt to determine the critical frequency of touch stimulation. The stimulations of pressure, pain and temperature are periodically interrupted by a rotating disc. The results tend to indicate that all sense organs obey the same fundamental laws. Cold, and especially warm, were not very successfully aroused by this method of stimulation. Pressure fails to respond at high frequencies and also at an intermediate zone of frequencies. The authors believe that superficial pressure responds at one zone of frequency, and deep touch or pressure at the other. Pain responds only at low frequency.

Piéron (78) discusses the general status of our knowledge as regards the conditions of stimulation and dimensions of experience in the field of touch. He concludes that we know much less in regard to touch than in regard to vision, and that, as a result of the complexity of the problems and the lack of adequate facts, general laws of touch cannot yet be deduced.

*Pain.* Different qualities of pain are distinguished in several investigations. Schriever (88) excites pain by a cold stimulus and

finds that the threshold of clear pain is about the same in all parts of the skin, varying only and inversely with the thickness of the corium. The threshold of dull pain, however, varies in different parts; wherever nerve branches rest near the surface of the skin, the threshold is low, and wherever they are deeper seated the threshold is correspondingly higher. The two varieties of pain also show differences in regard to distribution in the mouth cavity. Sensitivity to clear pain is greatest on the tongue and gums, and least on the walls of the cheek and lips; that to dull pain, although greater in general than on the skin, shows only slight differences in the different parts of the mouth. Schriever (89) states that the nerves which mediate dull pain are more sensitive to cold and pressure but less sensitive to warm than those nerves with which clear pain is correlated. The latent time and after-sensation period of dull pain are as a rule longer than those of clear pain. There are no significant differences, however, in regard to adaptation, fatigue, and recovery from injury. Using electrically heated platinum wires, Schriever(87) determines the differential threshold of pain at different intensities. His discovery that the relative difference limen is about one-sixth or one-seventh at all intensities indicates that Weber's Law holds in intensive stimulation of pain.

Bazett and McGlone (8) puncture the skin, arteries, veins, deep fascia, periosteum, etc., with needles, and arrive at the conclusion that pain on the skin differs from that excited in the walls of the arteries and deeper tissues. The latter type of pain is characterized by a dull ache, is less acute, but also less bearable than superficial pain. Deep pain is also often accompanied by such reflexes as nausea, etc., which are under the control of the autonomic nervous system.

Kiesow (61) comes to the defense of von Frey's theory of pain as against that of Goldscheider, who asserts that tactile nerves mediate pain. He indicates a number of distinguishing psychological characteristics of pain and touch, and asserts that, in view of the manifold differences, separate sense organs for the two qualities is a necessary assumption.

Woolf (95) regards pain as the result of excessive stimulation of any sense organ. He launches invectives against the view of MacKenzie and others who think that, owing to the fact that in surgery the exposed organs are insensitive to pain, it is not a visceral experience at all, but is aroused as a result of transmission of impulses from the viscera through the nervous system to the somatic organs

in which the experience has its origin. Woolf points out that pain can actually be felt internally, and that the supporting evidence for MacKenzie's view consists of exceptional cases. Lapinsky (63) advances the view that referred pain is an instance of irradiation through the vascular centers of the thoracic cord.

*Quantitative theory of feeling.* Titchener's touch pyramid is criticized by Nafe (72) on the ground that certain dimensions represent qualitative differences and others quantitative or intensive gradations of touch, and that those experiences are in no real sense simple and unanalyzable. He points out that all cutaneous experiences are patterns of brightness of varying degrees of complexity, that they bear resemblance to timbre in tonal complexes, and that affective and emotional experiences are complexes of felt (sensory) experiences. Owing to the psychological kinship of cutaneous, kinesthetic, organic, affective and emotional experiences, Nafe suggests that the term "sense of feeling" is the most appropriate caption under which to classify them. In another place, Nafe (73) denounces the prevailing tendency to apply the doctrine of specific nerve energies in the field of touch on the ground that no satisfactory positive evidence in support of that view is available. Against this traditional view, which assumes separate sense organs for the several qualities of touch, he submits a quantitative theory (74) which dispenses completely with the concept of quality. The different qualities are accounted for on this theory in terms of quantitative variations of intensity, duration, density and extensity. Pain is always aroused at high, contact and tickle at low intensities of stimulation—per unit area—of the skin. The temperature qualities are less satisfactorily woven into the theory, but owing to the fact that the two thermal qualities are not coexistent and are seldom, if ever, aroused except along with pressure, it is suggested tentatively that they represent opposite and special modes of stimulation of the same pressure-pain nerves.

*Touch localization.* Cole (12) is concerned with the problem of errors in touch localization. When he uses Weber's second method, he finds constant errors in certain regions but not in others. The glass plate method, in which the localizing movement is terminated by a glass plate which rests above the skin, yields constant errors at all regions. Progressive stimulation, whereby the second stimulus is applied at the point at which the first one was localized, and the third in turn where the second was designated, gives results which exaggerate the tendencies to error characteristic of localizations by

the ordinary method of stimulation. As regards the matter of fatigue of pressure spots, Cole shows that a king-spot may be stimulated ten times in succession without resulting increase in the size of the error of localization. Von Skramlik (90) points out that his discovery that localization of pain is less accurate than that of touch contradicts flatly results published by Kiesow and by Ponzo. He believes that this discord in experimental results is not to be attributed, as Kiesow thinks, to a difference in the method by which the subject localizes the stimulated spot, but to the fact that Kiesow and Ponzo aroused complexes of touch in which there were both pain and pressure components, whereas he secured pure pain sensations. Mayer (70) finds that touch complexes of pressure and pain are more accurately localized than either pure pressure or pure pain; and that the error of localization is greater for pure pain than for pure pressure.

*Two-point discrimination.* Rein and Strughold (81) find that the threshold of duality for cold varies in different parts of the body. It is smaller than that of warmth in the same area, but is, on the contrary, always larger than that of pressure. Malamud (69) tests the two-point sensitivity to pain and to pressure, determining (1) the point at which the impression first begins to change into a distance, (2) the point at which the impression appears as a distance bounded by two points, (3) that at which the distance corresponds more or less accurately to the actual separation, and (4) that just above which two points are consistently felt. The pain values are lower than those of pressure in the first three, but in the last case the threshold of pressure is lower than that of pain. Friedman (31) finds that the spatial threshold of duality decreases up to the age of twelve, after which it increases. He believes the increment after twelve depends on intellectual rather than on anatomico-physiological factors. Richardson (83) discusses results of experiments on double touch and points out that best representation of the thresholds in cases where sensation is confused by vagueness and uncertainty is in the form of a regression curve giving mean sensation as a function of stimulus.

*Tactual perception of form.* The ability to apprehend form by touch has been investigated by several persons. Working on the volar surface of the forearm, Zigler and Northup (96) find that forms of tactually presented figures are not definitely perceived in more than about 50 per cent of the presentations; that triangles are more easily apprehended than squares, hexagons and diamonds; and

that the main dimension of a figure must be 12 to 15 mm. for the form to be perceived. Zigler and Barrett (97) find that outline figures are better apprehended than solid, and the latter in turn than point figures. The tip of the finger is a better receptor of form than the palm, which in turn is better than the forearm. The perception of form is not immediate, at least in a great many instances, but develops gradually through well delineated stages. Bose and Kanji (10) and DeGowin and Dimmick(20) emphasize the rôle of both visual and tactual imagery in the process of perceiving tactually presented forms. Révész (82) points out that visual and tactual processes are intimately fused in the perception of form; and that the parts of a whole are not spontaneously organized but are arranged into a form by a relating activity. Rosenbloom (84) also finds that closed figures are more clearly apprehended than open figures, and shows that a gap in a figure equal to the two-point limen in that part of the skin is not perceived as a separation or gap.

*Post-operative sensitivity of the skin.* Sir E. Sharpey Schafer(85) had the ulnar branch of the internal cutaneous nerve transected in the left, and the same nerve crushed with the forceps in the right arm. Owing to accessory nerve supply to the same regions, complete anesthesia failed to follow in either case. However, a condition of hypersensitivity, especially to pain, prevailed. Recovery of sensitivity was complete in four months on the side in which the nerve had been crushed, but in more than nine months the other side had not completely regained its normal sensitivity. Schafer (86) selects the little finger as the region in which complete denervation is possible. The nerve is crushed on one side and divided on the other. Total insensitivity results in both little fingers. Recovery is complete in three or four months on the side in which the nerve was crushed, but normal sensitivity has not taken place in more than fifteen months on the other side. It is suggested that in the former case the nerve sheath was not destroyed so as to prevent the ends from easily reuniting, while in the case of nerve division the reunion takes place, if at all, under less favorable conditions. Sensitivity to pain makes complete recovery first, and that to touch last. Schafer alleges that protopathic sensibility is an unnecessary postulation. Fifteen years after the operation, Duliere (21) tests the sensitivity of a patch of skin which was transferred from the arm to cover an ulcerated place on the cheek. The same type of sensitivity is found to exist on the graft as on the corresponding region of the other cheek, but the latter shows better chronaxie. However, the two

biceps, from one of which the piece of graft had been taken, exhibit the same chronaxie. Eidelberg (22) reports that in several cases of syringomyelia, sensitivity to either wetness or dryness is reduced without affecting the other quality, and that this altered sensitivity exists only in certain parts of the body. Hoff and Schilder (52) report that victims of *tabes dorsalis* or of lesion of the cerebellum, and to a lesser extent normal subjects sometimes, experience an underpropping of the fingers when the hands are extended in such a way that a small space is left between the fingers or when the arms are extended and the hands are closed together. It is suggested that this is an important clinical symptom of organic illness, owing to the fact that it is accentuated in cases suffering from lesions in the cerebellum.

*Nature of discharge of sensory impulses.* Several investigators present graphic records of the action currents which are released when the skin or a muscle is stimulated in various ways. While one investigator finds that the records of different modes of stimulation are essentially of the same type, others offer results which point to at least two varieties of discharge of sensory impulses.

Adrian (1) used a capillary electrometer to record the changes of electrical potential in the discharge of sensory impulses, in the nerve-muscle preparation when excited by tension, and in the cat's toe-pad when stimulated by pressure, contact, movement of hairs and prick of a needle. He finds that the action currents to pain and to pressure stimulation are of the same type. In all cases they consist of a series of impulses which obey the "all or nothing" law, *i.e.*, they do not increase in extent with increase of intensity of stimulation. Variation of intensity produces changes in the frequency of impulses only. His technique is described elsewhere also (2, 3), where he again asserts that all sense organs in the skin respond by the same type of sensory impulse discharge. No qualitative differences, but quantitative differences only, such as variation in refractory period or rate of adaptation, are found. Fulton and PiSûner (32) show that irregular action currents may be detected in the galvanometric records of an extensor muscle, such as the knee jerk or stretch reflex, if the muscle is placed under slight initial passive stretch before the reactions are elicited. In explanation of this finding, they determine that certain currents are occasioned by end-organs arranged in parallel with the tension yielding elements of the muscle (muscle spindles) while others are produced by end-organs arranged in series (Golgi tendon organs). McGouch, Forbes, and Rice (67) secure synchronous galvanometric records of the

tension of the *tibialis anticus* muscle and of movement of the foot. While their results point in the same direction as those of Fulton and PiSûner, that action currents arise from impulses released by more than one kind of receptor, they fail to find sufficient evidence to assign the components of the record to specific receptors.

Gasser and Erlanger (33) suggest a new method for locating the fibers of the different cutaneous senses in a nerve trunk. They induce nerve block by (1) cocaine and (2) pressure, and find that the nerves are differently affected by the two types of block. The order of disappearance when nerve block is established by cocaine is pain, cold, warm, contact. While the results are somewhat less conclusive when nerve block is induced by pressure, the indications are that the order of disappearance is just the reverse of that for cocaine blocking.

*Galvanic skin reflex*. The nature of the galvanic skin reflex has been studied by a number of workers. Darrow (19) finds that this reflex varies in extent for sensory and ideational stimuli. There is a marked rise in the reflex response when a sensory stimulus is presented, but only a slight change occurs when ideational stimuli are used. The same authority (18) offers three modes of explanation of the fact that a feeling of warmth or flushing accompanies the galvanic skin reflex. There may be (1) a momentary acceleration of metabolism, or (2) increased thermal permeability of the tissues, or (3) acceleration of the capillary circulation. Gildemeister (42) finds that the psychogalvanic skin reflex is occasioned by differences in the amount and rate of polarization in different parts of the skin. In another place (43) he says the skin acts as a polarization cell in which electricity is stored up by shift in ion potential. Hahn and Lueg (48) determine that thermal stimuli release this reflex in cold blooded (frog) but not in warm blooded (cat) animals. Jeffress (55) finds that tension of the arms or clenching of the hands affects the psychogalvanic skin reflex. The parts under tension are positive to parts of the body not under tension. Electrical potential is assumed to be more alike in symmetrical than in unsymmetrical parts of the body. A new electrode, which can be used with liquid or paste substances and which eliminates accidental deflections of customarily used electrodes for the psychogalvanic skin reflex, is described by Lauer (65).

*The sense of vibration*. Katz (57) again advances arguments in support of the view that the sense of vibration is the genetic antecedent of both touch and hearing. He shows (58) that the senses of

touch and vibration are distinguished on the ground that the latter has a significant dynamic component which the former fails to exhibit. In normal subjects, sensations of vibration are aroused along with auditory sensations which tend to obscure the sensations of vibration. But in deaf subjects, such as Helen Keller and Eugene Sutermeister, who are able to enjoy and to discriminate between different kinds of music, the rôle of the vibration sense is clearly indicated. Katz and Noldt (59) point out that they had no intention, in connection with their work on the frequency threshold of vibration sensations, to give the impression, which von Frey got, that sensations of vibration represent a special kind of sensation of movement. Just perceptible vibrations give rise to experiences in which the perception of movement is not directly perceived. Katz and von Götzen (60) arrange an experiment which puts to a test the physician's method of diagnosis of the condition of deep tissues. Figures are chiseled out of, or embossed on, a lead plate, which is then covered with a cardboard through which the form is to be tactually apprehended. The forms can be determined through the joint medium of vibration and auditory sensations, or they can be determined through the sense of vibration alone. The sense of vibration is here designated a distance receptor.

Petzoldt (76) performs experiments having to do with localization, threshold values and masking of vibration sensations. Localization is accurate both in the hands and in the feet, unless the members are crossed, in which case confusions of various kinds occur. Threshold values are of the same magnitude in the hands and feet. A stronger vibration sensation masks completely a weaker one, but if the former is terminated while the weaker one continues there is an illusory perception of movement; the vibration sensation appears to move from the point of stronger to that of weaker stimulation. McKinley (68) shows how a tuning fork may be adapted to the purpose of determining thresholds of vibration. Knudson (62) develops a technique for determining the sensitivity of the skin to vibratory stimulation. It consists essentially of a vacuum tube oscillator which generates frequencies between the limits of 10 and 50,000 per sec. With this instrument he determines the lower limit of sensitivity to vibration at 12 to 15, and the upper limit at 1,600 per sec. Gault reports in one place (36) that the upper limit is above 2,000, and in another (37) places it at 2,700 vibrations per sec.

Several kinds of teletactor are described by Gault (36). By the aid of these, deaf and normal subjects can learn to identify words in

terms of variations of weight or intensity, roughness and total vibratory patterns of their tactual impressions. Crane (15) finds that vowels and diphthongs can be discriminated through the vibratory patterns of roughness received through a teletactor. He finds an inverse ratio between intensity of tactual stimulation and ease of discrimination. Gault and Crane (40) use a multiple unit teletactor with which to determine the order of difficulty in understanding the different vowel sounds. Gault (38) shows that, by the aid of the teletactor, a deaf lip-reading subject can understand about twice as many words as he can by using lip-reading alone. In another study by the same author (39), homophenous words were presented to deaf subjects who depended in one case upon lip-reading and in another upon vibration patterns produced by these words as transmitted to the teletactor. Barring a few exceptions, the sense of vibration proves to be the superior avenue through which to present these words for understanding.

*Kinesthesis.* The majority of the studies which fall under this topic are concerned primarily with problems of learning or judgment of space. They indicate the influence which varying degrees of activity or kinesthetic tension have upon rate of learning or upon accuracy of judgment of size and distance. Two or three studies only have a direct bearing upon the problem of the nature of kinesthetic experiences, or describe apparatus by the use of which investigation of such a problem may be made.

Von Frey, Grundig and Strughold (29) repeat Cohen's experiment in which after anesthetizing the skin by the injection of novocaine the last named found the threshold of deep pressure to be twice as high as previous to the use of the anesthetic. Von Frey and his associates inject novocaine subcutaneously and intramuscularly, and find that the threshold of deep pressure is uninfluenced in both cases. An apparatus by which muscular contractions in the living subject can be recorded is described by Pritchard (79). A light aluminum frame is fitted to the patella horse-shoe and connected with the end of a spring balance from which readings of the extent of shortening of the muscles in knee jerk responses can be taken. Franz and Watson (26) have designed an apparatus by which force of movement can be measured. The subject pulls against a spring, from the scale of which readings are taken. The units of the scale may readily be changed for different experimental requirements.

In connection with learning experiments, the rôle of kinesthesis has been studied both in the human and in lower animals. Bar-

low (7) finds that grade school children and college students memorize lists of words more rapidly when permitted to repeat the words to themselves than when explicit laryngeal reactions are suppressed by the act of holding a pencil firmly between the teeth during learning. The order of efficiency of the different methods of attack in memorizing the Miles elevated finger maze is found by Husband (54) to be: (1) verbal or counting, (2) visual, (3) combination of verbal, visual and motor, and (4) motor. Cox (14) finds that individuals who score higher in the Thorndike intelligence test tend to rely more on kinesthetic than on visual or mixed guidance cues in their performances on the Miles two-story maze. In performances on the same maze when the lower pattern is disoriented 90 to 180 degrees, the same writer (13) finds that reliance upon visual cues to be superior to that upon tactual or kinesthetic cues. Lashley and Ball (64) trained rats to run a maze, whereupon sensory function was altered by complete division of the dorsal or lateral funiculi. The animals were still able to run the maze in spite of serious sensory disturbance, but control experiments seem to indicate that these post-operative performances are mediated by some intraneural mechanism rather than by any directive kinesthetic or proprioceptive sensory cues. Johnson (56) studies individual differences in regard to the amount of pressure characteristically exerted in certain motor tests, such as tapping, and speed and accuracy of movement. Every subject tends to conform to one of the following types: (1) slight pressure throughout the performance, (2) initial rise in pressure with gradual decrease, (3) slight initial pressure with gradual increase, and (4) irregular changes in which high pressure tends to predominate. By clipping the vibrissae of rats, Fields (23) finds that tactual and kinesthetic factors have no determining influence upon the discrimination of form by the rat.

Other experiments throw light upon the way in which kinesthesis influences the phenomenology of space and time. Weber (93) determines that a distance reproduced on the Michotte kinesthesiometer under load appears to be longer, proportional to the amount of load, than one of the same physical extent without load. He also finds that the same interval of time perceived under strain appears longer, proportional to the amount of activity, than when it is passively perceived. Weber and Dallenbach (94) had their subjects trace areas, angles and arcs with differently weighted types of stylus. They find that, when traversed under load, the area appears to be enlarged,

the angle to be more acute and the arc to be more sharply curved than when traversed without load.

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# THE PERCEPTION OF VISIBLE MOVEMENT

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During the last two years the literature on the perception of visible movement has been concerned chiefly with (1) intensive studies of apparent and real movement in order to derive explanatory principles for the perception of movement, (2) further observations on various visual illusions and, (3) theoretical papers on the perception of movement. There has been a continued tendency to explain the perception of visible movement on a phenomenological basis.

## I. Experimental

De Silva (3) finds "that visual movement produced by successively appearing parallel lines, depends upon a complex arrangement of stimulus determinants to maintain it as a good illusion." The parallel lines were presented kinematographically. Experiments were carried out concerning the perception of movement as regards the size variable and such other factors as influence of varying intensity of light, addition and subtraction of members (stimuli), influence of varying pause, influence of varying exposure times, focussed vs. unfocussed stimulus, influence of varying distance between the lines, crosswise vs. up-down movement, influence of coloring stimulus, foveal vs. peripheral movement, and simultaneous movement in opposite directions. The following precautions are suggested for a study of the perception of movement: "Unless conditions are correctly arranged the phenomenon ceases to be perceived as movement and becomes inferred. Judgments upon optimal apparent movement made with a gross stimulus attitude are likely to be unreliable because of the influence of secondary attributes such as swiftness, jerkiness, greyness, etc. O's may wittingly or unwittingly adopt one or another aspect of the perceptual pattern as their primary criterion of judgment. Therefore, because observable secondary attributes vary as the stimulus varies, and because an O's criterion for judging optimal movement may vary, it follows that we should rely altogether on gross judgments upon the stimulus which produces ap-

parent movement." It is found that the time element is the most fundamental determinant of movement. The angular velocity, as measured from a subject's eye, and the duration of the sensation of movement are also greatly significant. The illusion of movement further depends upon such additional factors as the length of line, size of stimulus, brightness contrast between stimulus and background, color of stimulus, and region of the retina stimulated. In another investigation de Silva (4) studied the visual perception of movement by the use of a special apparatus which permitted the exposure against a black background, of two bright lines. The time interval between the exposures of the lines as well as their distance apart could be varied. Occasionally a line was introduced when the first line disappeared, moving towards and disappearing when the second line appeared, thus giving the sensation of an actual moving object. On other occasions the two lines alone were shown successively, with no actual movement of an object in the space between them. Experiments were conducted in order to determine the effects of physical differences, *i.e.*, variations in the distance between the lines; variations in the speed of movement and the length of the pause between the exposures of the two lines; variations in the exposure time and light intensity, and (2) to study some of the effects of central determinants, such as physical clearness, expectancy, sets, etc., on the perception of movement. Movement is characterized by its two fundamental attributes, namely, "movingness" and the "vehicle-of-movement." "Movingness" is closely related in experience with the attributes of extensity and protensity, and is comparatively independent of the attributes of quality and intensity; on the physical side it is most directly comparable to physical velocity. The "vehicle-of-movement" varies greatly in clearness. The relative clearness or obscurity of the "vehicle-of-movement" marks off the chief distinction between slow and fast real movement, and between real movement and apparent movement. The best conditions for the appearance of the illusion of apparent movement are short distances between objects, short pauses between exposures, and to a lesser extent, long exposure times and increase in the light intensity, while with real movement at high velocities the perception of "movingness" may disappear. The effects of the central determinants are emphasized as of marked importance. Under favorable conditions a single stationary line may be seen to move, a moving object may be seen as stationary, or movement may appear to be in the direction opposite to the actual direction. Introspection is found to be inade-

quate to give a complete account of the perception of movement, since so many significant details are never clearly represented in consciousness. Head's theory of schematism together with the help of three further concepts, *viz.*, attention, clearing-up, and clearness-status, serve as principles of explanation. Dimmick and Sanders (5) made an intensive study of the influence on the phenomenon of visible movement of two factors, *viz.*, the length of the temporal interval and the intensity of the stimulus; $0\sigma$, $30\sigma$, $60\sigma$, and $90\sigma$ served as time intervals, whereas "brilliant white," "good white," and a "dull white" denoted the three intensities used. The subjects were instructed to give an accurate description of the visual perception. Results show that the shorter time intervals give simultaneity, the longer ones succession, and the intermediate ones movement. However, when the instructions were changed to read, "You will be shown a stimulus which may or may not arouse a perception of movement, state whether you perceive movement," the percentage of perceptions for all the subjects was more than doubled. The former type of movement is called the "apprehension of movement" and the latter the "inference of movement." "Visible movement" is another type of movement whose basic sensory correlate "is an unsteady or flickering bulky-film of gray which in the case of the stroboscopic stimulus, consists primarily of projected 'central gray' modified in a particular case by the qualities of the stimuli and of the background and by perceptual images of the order of 'memory color' or 'tied images'." The frequency of optimal movement varies with the intensity of the stimulus, the percentage of cases of optimal movement at $30\sigma$ and $60\sigma$ time interval being increased by an increase in the intensity of the lights, but the result is not univocal. The results are in general agreement with those of de Silva (3, 4) and Higginson (18). In a study on reciprocal inhibition and reenforcement in the visual and vestibular systems, Travis (31) observes that under certain conditions the visual and vestibular systems seem to be active even though there be no immediate objective stimulus of movement. The apparatus used in this study made possible a simultaneous or separate movement of body and a fixated object. It lent itself to an analysis of the following conditions:

(a) Visual object and platform moving in same direction
(b) Visual object and platform moving in opposite direction
(c) Visual object oscillating, platform stationary
(d) Platform moving, visual object stationary

The observed hallucinations of movement of the body and visual

object is believed to be conditioned by a central factor possibly in conjunction with one or more peripheral factors. "The central factor appears to be very closely connected with both positive and negative responses and in certain instances seemed to re-enforce and in others to inhibit the peripheral excitatory processes." Guilford and Helson (15) obtained photographic records of eye-movements during the perception of the phi-phenomenon, which they interpret as showing that eye-movements do not play any essential rôle in the perception of hallucinatory movement. These findings are opposed to Guilford's earlier findings and those of Fisher (11), Stern (30), and Higginson (19), and others who accept the eye-movement theory as an adequate explanation for stroboscopic movement. It is interesting to note that Guilford's and Helson's and Higginson's subjects agreed in their introspective reports. Both sets of subjects report eye-movements and strain and kinesthesis during the perception of stroboscopic movement. Guilford, however, believes that "the only court of appeal is the objective record of what the eyes were actually doing at the time the movement was seen, unless one resorts to the theory that the phi-phenomenon is due not to overt eye-movement but to strains and incipient movements." It is further suggested that any general theory of apparent movement must take account of all the facts, not only of visual, but also of auditory and tactual movements from stationary stimuli. Rutten (29) obtained some interesting phenomena of visual movement in a study of the Müller-Lyer illusion. The elements of Müller-Lyer's images were successively and tachistoscopically cast on a white screen in a perfectly dark room. At the exposure of the figure and its parts, regular changes and apparent movements took place in the background. These movements are separated into (1) "phenomena which are the consequence of the tachistoscopic exposure of an object, and (2) form-phenomena, which must be considered as a result of the tendency to the formation of a new whole from collective data. . . . The movement which emphasizes the difference in length between the isolated line and the line of the figure is a consequence of the sudden apparition of a complex of which the spatial relations are overrated." Dunker (7) distinguishes between "induced" and "experienced" movement. Induced movements are those in which the objective stimulus remains stationary and the experienced movement is due to a shift of the surrounding objects or of the observer. When directing a stationary point of light on a large card and then moving the card to and fro, it seems that the point of light also moves.

Similarly, when two rows of several parallel lines are placed one above the other, and one of the rows is moved the other seems to move. In all cases, "phenomenal movement is a displacement in a natural system of reference." Guilford (14) gathered data from three observers to test the eye-movement versus the streaming theory for the explanation of autokinetic sensations. The moving spot was observed to leave a trail of gray or of a color complementary to that of the spot. Observations show that there is movement of a film over the whole field in an opposite direction to that of the spot, and that this film can be seen in various tints drifting across the face of the spot. The flowing streams are not those of Edridge-Green or of Ferree, they are streams which involve the entire retina at once. The spot moves toward and the film away from eye pressures. A change in eye-pressure produces a corresponding change in the direction of the spot. Streaming is not the cause of the eye pressures in question, because artificial streaming set up by a kymograph drum induces pressures in the same direction rather than in the opposite direction. Initial movement of the spot is about as often outward as inward. Evidence is found that differential fatigue and recovery of extrinsic eye muscles do not determine the direction of movement of the spot. Zietz and Werner (33) find that rhythmically or arhythmically presented auditory stimuli influence the perception of optical movement. Various figures containing arrows, irregular lines, and circles, were presented stroboscopically, accompanied by rhythmical or arhythmical tapping. It was found that auditory stimulation elicits optical movement or influences the form of the movement or of the moving object. Auditory stimuli exert a modificatory influence upon the perception of optical movement to the extent of changing the course of visual movement. Movement is believed to be the dynamic function of the entire organism. In a study on the visual perception of movement Bonaventura (1) confirms Exner's results which lead to the conclusion that the visual perception of movement does not presuppose the perception of a succession, such as luminous points. In Exner's sense this does not necessarily imply the existence of a specific "sensation of movement." There is no justification for calling the apparent change of object a "sensation of change." Ehrenstein (9) formulates the following laws of the perception of movement on the basis of material previously presented by him and others:

1. Law of activity of contiguous retinal areas. (Umfeldwirkung)
2. Law of Einstellungswirkung.

3. Law of the spatially-modifying force (raummodifizierenden Kraft) of primary and secondary movement.

Perception of movement belongs to the general class of experiences of relationship. Configurations arise out of a background of manifold visual forms. If one of these forms differs from the uniform rest in color, form, size, familiarity, in having long and thin points, or in being singled out by the observer, then it becomes the figure in relation to which the forms constitute the background. Musatti (25) presents data which do not bear out the conclusions reached by W. Ehrenstein in his studies on apparent movement. Ewert (8) inverted the visual field of view 180 degrees by means of specially constructed prismatic lenses. It was found that under these conditions eye- and head-movements resulted in a general rocking and swimming effect of the whole visual field. This movement was very apparent for several days during continuous inversion, then became less noticeable, but it appeared again after removing the lenses. Movement of visual objects was reversed from normal movement and much accelerated. The illusion of reverse movement was so strong that it could not be verbally inhibited even when the eyes were temporarily closed. Movement under these conditions is ascribed to the antagonism between old (normal) and new (necessitated by inversion) eye movements and the resulting antagonism between eye and head or body movement. Normally, compensatory eye reflexes keep the eyes fixated on an object during head movement. Under inverted conditions, however, due to the antagonism between eye and head reflexes, the new (necessitated by inversion) compensatory eye movements cannot keep pace with the head movements. It was also found that this new visual movement greatly influenced normal auditory movement. The following is a report from one of the subjects: "A car was heard to come from the right, moving toward the left. As soon as it entered the field of view the sound jumped over to the opposite side. It was now both seen and heard to travel toward the right. However, as soon as it passed out of the field of view the sound seemed to jump back and continued its course toward the left." Rexroad (28) suggests a theory that visual images and their movement are determined largely by the tensions in the recti muscles. It was found that if a subject fixated a point at one side of a large light spot and the spot was made to disappear, the after-image appeared to float away from the point of fixation. By testing fixation after some seconds it was found that eye-movement had occurred in the direction of the apparent movement of

the image. If eye movements took place in the opposite direction before the image appeared, its appearance would be delayed, and if they were set up after the image appeared it would be abolished during the movement. Guilford (17) describes a phenomenon of the momentary resting appearance of a revolving wheel in linear motion. It was observed that the wheels of a passing motor car were spasmodic in their movement, proceeding by alternate stops and starts. By fixating the hubs of the moving wheel, the spokes were seen to flash out in complete detail for a moment, the whole wheel appearing stationary. The eye movement theory is proposed as an explanation and then is further tested in the laboratory. A wheel was constructed from a black cardboard disc 25 cm. in diameter, with a white center 6 cm. across, and 16 white spokes each 1.2 cm. in width. The wheel was driven by a motor and its speed controlled by a rheostat. The speed most favorable for the production of the phenomenon was found to lie in the region of speeds at which flicker ceases and color mixture begins. The following report of one of the subjects exemplifies the nature of the observed phenomenon: "I got the spokes very definitely. Occasionally I got things like lightning flashes, light gray bars against a dark background. When I winked I saw all the spokes very clearly all the way around; it seemed to stop dead still." It was found that most of the flashes were accompanied by eye movements. But a considerable percentage of them were not. Since the stationary flashes seem to come rhythmically, it is proposed that time may phenomenally flow at a non-uniform rate, proceeding by starts and stops. And this, it is believed, may be in part responsible for the stationary phases in the turning wheels. It is further suggested that the eye movements themselves may produce the distortion of time. A similar phenomenon is described by Gradle (13), who reports that the propeller of an airplane whose tachometer reading swung between 1,650 and 1,675 revolutions per minute furnished the stimulus. The phenomenon was not obtained with direct vision. But as the visual axis was turned laterally (either right or left), a blur in the form of the arc of the propeller became visible. Upon increasing the angle, the general outline of the propeller blades became definitely visible. Between 40° and 50°, the blades were seen as individual, and for about 10° to either side of these limits, the blades were seen as a blur. No explanation is offered.

## II. Visual Illusions

Gaehr (12) and Packard (27) describe the "spoke illusion." Gaehr offers the theory that all our time experience is "quantitized." Ferree (10) offers the eye-movement theory as an explanation of the phenomenon. "When successive impressions are given to any portion of the retina at a rate which produces a fused or continuous sensation, a quick lateral movement of the eyes causes momentarily a resolution of the fusion into component sensations. . . . The movement of the eye momentarily interrupts the succession of the impressions on any given portion of the retina, therefore the combination of impressions is prevented and the components are sensed as separate." It is suggested that the illusion is easier to get in indirect vision because the limen of fusion is higher there than in direct vision. The illusion is enhanced by distant accommodation because this means a larger pupil, a more intense stimulus, and hence again, a higher limen of fusion. Guilford (16) describes the following three forms of illusory movement in a rotating barber pole: (1) The subject may see the tortional movement as it actually occurs. (2) The subject may see movement in the vertical direction only, horizontal movement is missing. "The total perception is of a non-rotating pole above and below the glass case." (3) "The observer may see a combination of horizontal and vertical movement, with one of the two components prevailing to a greater or less degree." Dufour (6) found that when fixating a star with an opera glass (eight-fold magnifying power) it was seen as unsteady and as moving slightly in all directions, whereas the stars falling on the periphery of the eye appeared immobile. The movement in the direct field of view was found to be due to the involuntary movements imparted to the glass by the hand. Lack of movement in the periphery is ascribed to the differences of visual acuity in the macular and peripheral regions. Miles (22, 23, 24) gives a clear description of a number of commonly observed illusions, such as those of the windmill, the motion picture, the waterfall, the picket-fence, the firelight (phi-phenomenon) and several associated with the movements of railroad trains. The windmill illusion is explained as due to a "reversible perspective" of figure and ground. Since the observer is accustomed to seeing a wheel continue to rotate in the same direction, the seen change in perspective of foreground and background causes the illusion of a reversible motion. The waterfall illusion is believed to depend on the objective condition of movement

of relatively large areas of the visual field. The visual experience rests on the tendency for the visual field to operate as a compensating system, balancing its parts one with reference to the other. Kampmeier (21) describes some of the conspicuous phases of the phenomenon concerning retinal pressure images and their Brownian-like movement which was first described in detail by Purkinje in 1819. Pressure upon the closed eyes is observed to produce a fantastic play of light and dark figures, the vividness of which depends upon a number of factors, such as the state of rest or fatigue of visual elements. The dominating impression is an involved checkerboard design consisting of thousands and thousands of facets. These are arranged with remarkable regularity and symmetry and the sequence in which these designs follow one another is unusually constant. The individual units oscillate or quiver with the rapidity and degree of excursion of Brownian motion. The geometrical harmony of the images suggests that they are related to the retinal cells.

## III. Theoretical

In considering various theories of visual perception of movement, Triepel (32) raises the question whether the physiological processes of the stimulated end-organ give rise immediately to the perception of movement or whether an additional central process is necessary to achieve this end. The possibility that the structure of the retina itself may contain features that further immediate perceptual movemen, is then considered. It is pointed out that several visual cells converge upon one bi-polar cell and several bi-polar cells upon one ganglion cell. The discontinuity of the excitation of the visual cells caused by the moving object is thus overcome by their flowing together in the inner layers. Since the retina is an extension of the cortex it may be assumed, following Ebner's suggestion, that the image of movement is directly created in the retina and then rises into a conscious perception by associative connections in the occipital lobe. Cords (2) criticizes Leiri's theory of the after-image of movement explained in terms of after-nystagmus on the following grounds: The after-image is a purely local process; it is confined to the region in which movement has been seen. The after-image varies with retinal locality. Its speed decreases when contours and contrasts are eliminated, and when the duration of observation is shortened; optokinetic nystagmus is not affected by these factors. Cords then advances the theory that optokinetic after-nystagmus is a consequence of the after-image of movement. In a critical supplement

to the theory of the immobility of objects in case of voluntary eye-movements, Hillebrand (20) defends her previously advanced theory of "absolute localization" (the fact that the apparent position of an object remains constant although its corresponding retinal area has changed) against the objections of E. Kaila, M. Wertheimer, and F. B. Hofman. Hillebrand holds that the process underlying absolute localization furnishes the key to the explanation of stroboscopic movement. Apparent movement resulting from the exposure of two stationary stimuli must be regarded as an "elementary" phenomenon with respect to stroboscopic movement. In explaining absolute localization use is made of the fact that apparent movement is not observed in the case of voluntary eye-movements. The displacement of the visual field does not affect the "absolute" position of objects; only the relative position of changes. In a theoretical discussion concerning the problem of geometrico-optical illusions Oesterreich (26) questions the justification for speaking of optical "illusions" from a phenomenological standpoint. We are not justified in identifying "physical nature conceived of in a Euclidean sense and the immediately given, sensory contents of consciousness." Lines are straight or curved according to whether they are straight or curved perceptually.

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